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[*Continued on page (III) of Cover.*

GUINDY
18 FEB 1963

ELECTRICITY IN COAL MINES: A RETROSPECT AND A FORECAST

By R. NELSON, Member.

[*Paper first received* 22*nd June, and in revised form* 27*th September*, 1938; *read before* THE INSTITUTION 1*st December, before the* EAST MIDLAND SUB-CENTRE 6*th December, before the* NORTH-EASTERN CENTRE 12*th December, and before the* NORTH-WESTERN CENTRE 13*th December*, 1938; *also before the* SOUTH MIDLAND CENTRE 2*nd January, before the* WESTERN CENTRE 9*th January, before the* MERSEY AND NORTH WALES (LIVERPOOL) CENTRE 23*rd January, before the* SCOTTISH CENTRE 24*th January, before the* NORTH MIDLAND CENTRE 14*th February, before the* WEST WALES SUB-CENTRE 23*rd February, and before the* SHEFFIELD SUB-CENTRE 15*th March*, 1939.]

SUMMARY

The paper gives, first a brief review of the use of electricity in coal mines from 1908 to the present time, secondly a statistical summary of the position as it now stands, and finally the author's view of possible future developments.

The early part of the period under review was a period of some difficulty. An average death roll from coal-dust explosions of more than 250 persons per annum over a period of 5 years, added to the fact that electricity was widely suspected of having been the originating cause of the most disastrous explosion in the history of British mining, namely that at Senghenydd Colliery, South Wales, in October, 1913, had the effect of causing the miners to call for the removal of electricity from the pits. Happily, by the application of systematic stone-dusting, a means was found of preventing the spread of an explosion of gas or coal-dust, and thereafter the miners' opposition lessened, at any rate in degree. It has not yet disappeared.

During the last 10 years the coal industry has been greatly assisted by mechanized mining and mechanical methods of coal-sorting. These, with normal development in other directions, have resulted in a total of 2 162 015 h.p. of motors installed in 1937, made up of just over 1 000 000 h.p. above-ground and the same below-ground.

Accident statistics are touched upon. It is recorded that taken over 10 years, 1927–1936 inclusive, electricity has been responsible for 224 out of 8 656 deaths, or 2½ % of the total loss of life in the pits. The position in respect of the number of electrical accidents has not improved during recent years, but at the same time the number of men exposed to the risk of electrical accident has steadily increased year by year.

The last section of the paper consists of a forecast of probable future developments. The author concludes with an appeal to electrical engineers to capture, if possible, the confidence of the miners.

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INTRODUCTION

The intention is to review the use that has, so far, been made of electricity in coal mines, and to attempt a forecast of the immediate future.

In the Presidential Address which Sir Richard Redmayne delivered to The Institution of Civil Engineers in October, 1934, he mentioned that in the year 1883, when he himself, as he expresses it, "made his bow as a coal miner," there was very little mechanical power of any kind in use below-ground. "It was most unusual," Sir Richard said, "to find mechanical power used for any purpose other than on the surface of the mine." Though steam and compressed air were both sparingly used below-ground, there was no electricity. But electricity also made its "bow" to coal mining in 1883, the same year as Sir Richard, for in January of that year an electrically-driven pump* was set to work below-ground at the Trafalgar Colliery, Forest of Dean, Gloucestershire, and, from all the available evidence, that was the first use of electricity for the purpose of providing mechanical power below-ground in a British coal mine. Electricity was first used for under-ground lighting at the Earnock Colliery, Hamilton, Lanarkshire, in 1881, and a specimen of the Swan bulb and lantern is to be seen in the Science Museum at South Kensington. Before that date oil lamps had been solely depended upon, though the author has seen a pit-bottom in the Durham coal-field lighted by town gas piped down the shaft from the surface, and it is on record that about 1760 an attempt was made to light the surface of a colliery by burning fire-damp piped from the coal-face.

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* It is stated in the *Historical Review of Coal Mining*, published by the Mining Association of Great Britain in 1924, that the pump motor was only 1½ h.p. Later, in 1886, a 29-h.p. electrically-driven pump was installed at the same colliery.

It seems perfectly clear that the year 1883 saw the introduction of electricity for power purposes to coal mining. From the middle 80's onwards it was used progressively for underground lighting, pumping, and haulage, so that by the end of the century the use of electricity below-ground had long ceased to be a novelty. Mainly in the form of direct current, at voltages up to 500, it was being freely used for motive power, and, by means of four or five 100/125-volt lamps in series, for lighting also, though somewhat tentatively.

The first 3-phase motor to be used below-ground appears to have been installed at Ackton Hall Colliery, Yorkshire, in 1898. In 1908, 10 years later, there were still many fewer 3-phase alternating-current than direct-current installations. A great deal of the 3-phase current then in use was supplied from the mains of public electricity-supply authorities: the North-Eastern Electric Supply Co. in Northumberland and Durham, the Yorkshire Power Co. in Yorkshire, and the South Wales Power Co. in South Wales. A few isolated examples apart, the power companies introduced 3-phase working to the coal industry, as for general industrial purposes.

Although electricity has been in use below-ground for more than 50 years, the first 20 years may fairly be described as a period of evolution and development. Towards the end of this period the advent of the 3-phase alternating-current system of working in the early 1900's gave an impetus to electricity in mines which has persisted, in spite of some drawbacks (to which reference will be made later), until the present date, for the whole of the territory has not yet by any means been occupied. By the end of the year 1908 the use of electricity in coal mines had promised to become so general that the Government of the day felt it necessary to appoint an Electrical Inspector of Mines, whose duty was to administer an already existing code of "Special Rules" and generally to supervise the distribution and use of electricity in mines from a safety standpoint. The credential which the author possesses for dealing with the subject of this paper is that of having held the office of Electrical Inspector of Mines for more than 10 years.

It will be convenient to begin this retrospect in the year 1908, and to divide the paper into four sections:

1. The use of electricity in coal mines from 1908.
2. A statistical review of progress from 1912, when statistics were first available, to the present time.
3. Safety Regulations.
4. A forecast of probable future development.

(1) ELECTRICITY IN COAL MINES FROM 1908 TO 1938

By the year 1908 the use of electricity in coal mines, though still in a general sense new, had, nevertheless, become established, with 20 years of development behind it. It may be of interest to describe the situation a little in detail at that time.

(a) Colliery Electrical Equipment 30 Years Ago

A normal colliery plant in 1908 would consist of a low-speed engine driving by belt or rope a direct-current generator, or alternatively a high-speed engine direct-coupled also, as a rule, to a direct-current generator. Wire-armoured cables were carried down the shaft, but there, speaking generally, the armoured cable ceased. Switchboards were of the panel type, with bare copper conductors and knife switches, or in a few instances cast-iron distribution boxes with fuses of the porcelain-handle type might be found fixed at the shaft bottom. In either event, current was carried in-bye therefrom by means of ordinary vulcanized-rubber cables, taped and braided but without armouring. The cables, run one on either side of the road, were secured to the roadway supports, usually timber props, by means of rope or leather thongs designed to break readily in the event of a fall of roof. They broke frequently in practice without that encouragement. In-bye the cables would end at a haulage motor or pump. Possibly, in a few instances, they would end on the roadside at a "gate-end switch" for the purpose of controlling the supply of current to electrically-driven coal-cutting machines, which were beginning to make headway. Compressed air and electricity were used about equally for coal-cutting, and a few compressed-air driven conveyors of the "shaker" type might be found.

The means commonly employed for controlling the supply of current at its point of application differed very little from surface practice. The main switchgear was sometimes, but not often, metalclad. Even when metalclad there was seldom anything about it to show that it had been designed to suit underground conditions. "A square peg in a round hole" accurately suggests a measure of the suitability of much of the electrical plant installed below-ground 30 years ago. Little interest would, however, attach to its description in detail; "electricity in coal mines" was in a state of transition. Electrical and mining engineers had still to educate themselves and each other: if the former had not yet grasped the differences that exist between surface and underground conditions, the latter, sound enough as mechanical engineers, had no knowledge of electricity and some amongst them harboured the delusion that bell-hanging methods could usefully be imported below-ground. The colliery electrician, often in those early days earning a niggardly wage, was frequently left without adequate supervision. Other than himself there was no one who understood the details of his work, with the result that he won little appreciation and encouragement for his often very strenuous efforts. He was looked upon, and looked down upon, as the representative of a "string and putty" business. In these depressing circumstances few gleams of managerial favour lightened the colliery electrician's daily task, but no objection was raised to his wandering about the mine at will. All that was asked of him was that his "electrical gadgets" should work, as, incredibly in some cases, they nearly always did. An agent so quietly effective was easily overlooked.

(b) The Responsibility of a Colliery Manager

It should be added that it is not suggested for a moment that avoidable risks were, in those early days, lightly undertaken, or that the likelihood of accident was widespread. That suggestion would do grave injustice to the colliery managers of the time. Electricity was not used below-ground except in places where, so far as could be foreseen, the risk of fire-damp was strictly negligible. The colliery management bears the dual burden of technical responsibility for the working of the mine and legal responsibility for the avoidance of accidents, and from this exceedingly wide range of responsibility it results that colliery managers will not willingly incur unnecessary risks, so that their attitude towards new and, from their point of view, untried devices is essentially conservative.

(c) A Series of Colliery Disasters: The Coal-Dust Menace

During the period immediately under review it so happened that coal mining was at a very interesting stage in its long history. The growing use of electricity during the years 1908–1914 was so unfortunate as to coincide with a series of disastrous colliery explosions. It had long been realized that though the original ignition in a colliery explosion might be of fire-damp, the explosion was reinforced, and the devastation throughout the mine mainly produced, by the ignition of clouds of coal dust. The disturbance and subsequent ignition of coal dust, long settled on the roadways and in nooks and crannies in roof and sides, sometimes carried the flame of the explosion through every roadway in the mine. In little more than 5 years between August, 1908, and October, 1913, there were seven major colliery disasters,* causing the loss of 1 277 lives, an average of 250 per annum, and the miners' leaders of the time were firmly convinced that some at any rate of these accidents were due to the presence of electricity in the pits—" this mysterious agent " as they called it 30 years ago—and they used every effort to establish their point of view. An effective remedy to prevent gas and coal-dust explosions, or at any rate to limit their extent, became more than ever an urgent necessity. Happily a successful remedy was ultimately found; partly by the obvious precaution of reducing the formation of coal dust and by removing it as far as possible from the mines, but mainly by diluting the irreducible minimum by adding stone dust to it in at least equal quantity. The stone dust, finely ground, is brought into the mine and systematically and evenly spread over haulage roads and other places where coal dust normally accumulates. It was proved conclusively by experiment that a mixture of stone dust and coal dust in, or about, equal parts is extremely difficult, almost impossible, to ignite. This remedy, the result of a long experimental research begun by an association of coal owners and continued under the aegis first of the Home Office and later of the Mines Department, has proved to be so successful that since stone-dusting became part of established mining practice 20 years ago, there have been few colliery explosions on the scale unhappily common immediately before the war. Stone-dusting does not *prevent* the ignition of gas; what it does is to prevent what may have been the ignition of a small pocket of gas from becoming a coal-dust explosion, spreading hundreds, possibly thousands, of yards throughout the mine. Thus, by damping down and limiting the range and extent of a gas or coal-dust explosion, a long step was taken towards removing what was, and still remains though in lesser degree, a serious menace to the life of the working miner. The case for stone-dusting is amply supported by mining statistics. Between the years 1901–1936 there were in all 37 major colliery explosions.* Of these 18 occurred in the first half-period (1901–1918) and 19 in the second (1919–1936), and of 2 424 lives lost, 1 766 were lost during the first half-period when stone-dusting was unknown, and 667 in the second half-period during the course of which stone-dusting became general and was indeed made compulsory under the Coal Mines Act. Apart from improvement in the general standard of ventilation and the compulsory use of " permitted " explosives in certain coal-seams, there has been, so far as the author is aware, no other known alteration of conditions.

Though the statement would not be applicable within the inner circle of the coal-mining industry, it is true to say that something—perhaps their own natural modesty, or possibly because only time could confirm results—seems to have deprived the Government Department concerned and the mining engineers who assisted with experience and advice, of the whole of the credit which is justly their due for a result of far-reaching importance; but no such consideration need deter the author, as an electrical engineer, from congratulating all who were concerned with the experiments upon their success, and upon an outlook from a safety standpoint so improved as to be comparable with the improvement which followed the introduction of the Davy safety lamp. It is certain that had the coal-dust danger remained unrelieved, the growth of the use of electriciy in coal mines would have been seriously hampered. Before the research, and later before the importance of the results had become thoroughly appreciated, if there was any electricity at all in use in the near neighbourhood of the suspected point of origin of a colliery explosion, it was difficult to persuade the miners to consider any other agency as the possible cause. Two of the explosions which occurred during the dark period 1908–1913, namely those at the Hulton Colliery, Lancashire, in 1910, and the Senghenydd Colliery, South Wales, in 1913, accounted for the loss of more than 780 lives between them, and in each case prior to the inquiry " electric sparking " was under grave suspicion of having been the originating cause.

(d) The Senghenydd Explosion and the Miners' Distrust of Electricity

At Hulton Colliery the official report on the cause of the explosion by the Chief Inspector of Mines placed its origin in a part of the mine where there was no electrical plant of any kind, and it was definitely stated that " the use of electricity in the mine had no bearing on the disaster." At Senghenydd Colliery the inquiry seemed to determine the place of origin beyond reasonable doubt and within narrow compass. The suspected place of origin was on an incline at the foot of which was found an electric bell of the trembler variety used for signalling. Though the use of electric signalling apparatus was widespread there was no other electrical plant in the mine. The bell itself was not suspected of having originated the explosion; what was suspected was sparking at the point where the signalling wires were bridged or otherwise short-circuited some distance up the incline for the purpose of signalling in the ordinary working routine. In accordance with general practice the signal wires were bare, that is uninsulated. The evidence clearly showed that the explosion immediately followed the ringing of the bell at the foot of the incline, and in the absence of any other equivalent of a naked light in the mine (all the safety lamps found in the district were subsequently tested and proved to be in good condition) the chain of evidence seemed to be unusually complete, but doubt was expressed whether sparks obtained by bridging signalling wires were, as it was expressed, " intensive enough " to ignite a mixture of fire-damp and air. Though informed opinion had little doubt at the time, and though the bell in question was used experimentally in conjunction with a short length of signalling wire to ignite a mixture of coal gas and air specially prepared, the contrary was argued with considerable force and the final report of the Chief Inspector of Mines was indeterminate. One result of the Senghenydd Inquiry was, however, the appointment of a Committee to investigate the whole question of the use of electric signalling apparatus in coal mines. The miners argued, logically enough, that if, as seemed by implication to be admitted, signalling wires and signalling apparatus were potentially dangerous, how much more so must be power and lighting cables and power and lighting apparatus?

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* Accidents involving the loss of 10 lives or more.

* The 29th Annual Report of the Chief Inspector of Mines for the year ended 31st December, 1936, page 186.

Mainly through the patient work of Prof. W. M. Thornton (Past-President) and Dr. R. V. Wheeler, now Director of Research Stations of the Safety in Mines Research Board, the investigation of the Committee attained its object, first by ascertaining and defining the conditions necessary to produce " non-intensive " sparking, and secondly by designing electric signalling bells and connections which can safely be used even though surrounded by an explosive mixture of fire-damp and air. The experiments, which afforded a complete solution of the problem, are described by Prof. Thornton in his paper " Some Researches on the safe use of Electricity in Coal Mines,"* and it may here be said that the solution of a number of mining problems associated with the use of electricity owes much to Prof. Thornton's skill and perseverance during the whole of the period under review. The Institution of Mining Engineers recognized Prof. Thornton's work in 1925 by conferring upon him the Gold Medal of the Institution, " Honoris Causa," in recognition of his individual contribution towards safety in coal-mining.

(e) The Lessened Risk of Explosion: the Record of Electricity over 20 Years

Returning to the general question of remedial measures and their application, in discussing possible causes the morning after the Hulton disaster a newspaper of wide influence* emphasized the fact that " to discuss whether this agency or that was the possible cause of a disaster is equally to condemn them both." It was added that " we must not take a decent minimum of precautions but every possible precaution that ingenuity and science can suggest, and, so long as we omit one, no one can look into his domestic fire with a clear conscience." The comment was, and remains, just and appropriate. If a possibility existed which could not be dismissed it stood condemned, so that the agitation which arose for the complete removal of electricity from all mines where safety lamps were compulsorily in use was at least understandable. New and more stringent Regulations were drafted and came duly into force in 1913, but the tension remained until the appearance and gradual growth of a greater feeling of security which followed relief, or partial relief, from the coal-dust danger. Thereafter, as the records show, the rate of growth of the use of electricity increased. It may also be said that at the same time electricity began to be regarded with less disfavour by the miners, though even at the present time suspicion has not died out. Within a few days of the serious explosion at Markham Colliery, Derbyshire, in May of this year, which travelled some hundreds of yards, the Member for Spennymoor, Co. Durham, though necessarily without knowledge of the actual facts, raised the question of " coal-cutting by electric machinery " in the House of Commons, urging the Government not to wait for the Report of the Royal Commission on Safety in Mines, then sitting, " but to take some definite action to prevent the explosions and casualties in coal mines which resulted from the use of such equipment." Though the only satisfactory answer would be a complete denial that " explosions and casualties " occur at all owing to " the use of such equipment," actually over a period of 20 years from 1914 to 1934 there were 16 fatal ignitions of fire-damp associated with the use of electrically-driven coal-face machinery, causing the deaths of 53 persons, an average of 2·65 deaths per annum. The number of casualties is 53 too many; but, for comparison, during the same 20 years there were in all 260 fatal ignitions of fire-damp of all degrees of magnitude and from all causes, resulting in the deaths of 1 262 persons, an average of 63·1 per annum. Such is the record of electricity—4·2 per cent of all deaths from explosion—over 20 important years. Since 1934, as will appear later, the record has not improved.

(f) The Economic Importance of Machine Mining

Reviewing the position of electricity in mines in 1926 the author remarked† in passing that there seemed then to be few places where the extended use of machinery had a more promising field than at the coal-face. The point was made that the coal-face worker's task is physically the most severe, as well as the most dangerous, of all underground occupations, yet during the post-war period to 1926 the rate at which manual labour at the coal-face was being displaced by coal-cutting and coal-conveying machinery was disappointingly slow. In 1926, at a time when the gradual shrinkage of the output per underground worker was one of the difficulties of the mining industry, less than 24 % of the total output of coal was machine-cut; but following the great coal stoppage of that year improvement set in. There was at once a marked increase in the use of coal-face machinery, that is of coal-cutters and coal-conveyors. In mining, as in every other industry in which labour cost is a high proportion of the total cost of production, the problem of cost reduction is that of increasing the output of the individual worker. In mining, this problem is specially important because labour represents very closely 66 % of the total cost of production. There has consequently been a very rapid growth in the number of coal-cutting and coal-conveying machines in use during the last 10 years, a result which has gone far to save the coal-mining industry from trials which would certainly have been more severe had not this opportunity for the extended use of mechanical power been available. Electricity has played an important part in this development.

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* *Journal I.E.E.*, 1924, vol. 62, p. 481.

* *Manchester Guardian*, 15th October, 1910.

† *Journal I.E.E.*, 1926, vol. 64, p. 1014.

(g) Improvement in the Design of Colliery Plant

During the whole of the period from 1908 onwards development in the use of electricity below-ground was constantly, if slowly, at work. More and more apparatus intended for use below-ground was specially designed to meet the conditions. Coal-cutters, to take the classical example, designed with due regard to the rough conditions and the inconsiderate usage they frequently receive, have become highly specialized and very efficient machines, and due attention has also been given to motors for winding, haulage, pumping, and all other colliery purposes. The influence of the electric drive is seen very clearly in the design of modern mining machinery. Naturally such electrical plant as cables, transformers, and switchgear, was given due attention, so that plant of all kinds specially designed for underground use has long been obtainable.

A whole paper might be written on the subject of the improved design of mining electrical plant. The case of mining switchgear, in particular, is of great technical and general interest, as the *Journal* of this Institution testifies, but there is one fact which the author has never seen anywhere recorded, namely that though the now universal metal-clad switchgear was conceived and designed in the interests of safety and security for power-station operation on the surface, its first widespread use, beginning 30 years ago, was below-ground in coal mines. The original designs for small-capacity switches were obviously suited for colliery work, and it is true to say that metal-clad switchgear became widely used below-ground some years before its merits received general recognition on the surface. In this way colliery practice assisted surface practice, and that that was so was largely due to the untiring advocacy of the late H. W. Clothier. In 1908 it was common to find an installation below-ground in which no single item of plant was metal-clad. In 1938, in any modern installation, there is hardly a single item of plant which is not metal-clad. Writing in 1908 on the subject of "Switchgear for mines"* Clothier commented on the fact that at that time "good enough for a colliery" was of the nature of derisive praise. He held, and even at this distance of time the author respectfully agrees, that no work should require any better recommendation of its quality than that it is "good enough for a colliery." That ideal Clothier consistently and successfully followed, so that his name cannot with justice be omitted from any list of those who, in the course of their daily activities, have made contributions of importance towards safety in coal-mining.

(h) The Flame-proof Enclosure of Electrical Apparatus

In 1922, by the enterprise of the Mining Department of the University of Sheffield, it was possible to have motors and switches tested for flame-proofness. This work was successfully carried on for some years, until, in 1930, it was transferred by arrangement to the Mines Department, and official certificates of flame-proofness are now issued based upon tests at the Department's Testing Station, Buxton, Derbyshire.

The principles governing the design of flame-proof enclosure were first laid down by Dr. E. H. Beyling on the basis of experiments carried out by him at Dortmund in 1905, and except for alterations in detail and some development in technique the same principles still hold good. The official definition of a flame-proof enclosure is as follows:—

> "A flame-proof enclosure for electrical apparatus is one which will withstand without injury any explosion of inflammable gas that may occur within it under practical conditions of operation within the rating of the apparatus (and recognized overloads, if any, associated therewith) and will prevent the transmission of flame such as will ignite any inflammable gas which may be present in the surrounding atmosphere."

That is to say, the design of a flame-proof enclosure must be such that in the event of inflammable gas being ignited within the enclosure, flame must not pass out so as to cause the ignition of inflammable gas surrounding it. Further, the enclosure must resist the effect of an internal explosion without evidence of distress, and must be capable of resisting and containing safely successive internal explosions without adjustment or repair. There is herein the assumption that gas may either enter from without or be produced within the enclosure by normal use of the apparatus; for example, an oil-immersed switch or controller. Flame-proof enclosure does not imply "gas-tight" enclosure, which is impracticable in many cases. The term "gas-tight," therefore, though frequently used, is in this connection a misnomer. An enclosure is tested with all its component parts assembled as for use, and if there is more than one internal compartment each compartment is, if possible, tested separately. An enclosure may be rejected as having failed to pass the tests for either of the following reasons:—

(*a*) If the structure suffers injury or shows evidence of distress as a result of the pressure developed therein.

(*b*) If inflammable gas or vapour surrounding the enclosure is ignited.

On successful completion of the tests, the enclosure is re-examined and a report is issued. In general, the report covers a description of the apparatus and a summary of the test conditions and test results.

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* *Electrician*, 1908, vol. 61, "Mining Issue," 10th July, 1908, p. 82.

(i) The Electrical Equipment of a Modern Colliery

In a present-day installation power is commonly transmitted underground as 3-phase alternating current at 3 000 volts, and distributed at pressures ranging from 400 to 650 volts. The switchgear, transformers, and motors are, as mentioned above, specially designed for underground use, and all metallic outer coverings are effectively earthed. All the circuits in a modern colliery installation would be protected by quick-acting safety devices designed to open circuit immediately a fault begins to develop, with advantage from an operation as well as from a safety standpoint.

The average horse-power of motors installed per colliery, 358 h.p. in 1912, had grown to 1 592 h.p. in 1937, but large collieries have as much as 6 000 or 7 000 h.p. of motors installed above- and below-ground. The total horse-power of two or three of the larger all-electric collieries (which means, broadly speaking, those with electric winders supplied from transmission mains) is upwards of 10 000 h.p. Where electric winders are in use, the horse-power installed on the surface is usually much greater than that installed below-ground, and the peak load may, on occasion, be as much as 4 000 or 5 000 kW. A colliery in the Nottingham coal-field returns a total of 10 240 h.p., of which 8 850 h.p. is installed on the surface, including a large winding motor. The motors installed below-ground amount to 1 390 h.p., made up as shown in Table 1.

Table 1

	h.p.
Haulage	700
Pumping	190
Coal-cutting	300
Coal-conveying	200
Total	1 390

A neighbouring colliery similarly equipped has much the same figures except for 50 % more horse-power of coal-cutting machinery.

(j) A Summary of the Situation as it now exists

To sum up, the present position is such that though electricity in mines has yet to gain the full confidence of the miners, given a continuance of the reasonably high standard of maintenance which now exists (and upon which safety chiefly depends) there seems no reason to doubt that it will steadily improve its present record and reputation. That should be the objective, for electricity is now so well-established as to be almost an essential agent in nearly all operations of importance at a modern colliery. The ease and economy with which electricity can be applied, and the fact that its application, though needing care, is entirely without inconvenience to the working miner, are great inherent advantages. One natural result is that the colliery electrician, now the colliery electrical engineer, is no longer, or at any rate he is in less degree, the Cinderella among mining officials.

(2) A STATISTICAL REVIEW OF PROGRESS FROM 1912 UNTIL THE PRESENT TIME

The number of mines at work has remained very nearly constant for some years. In 1937 there were 2 120 mines at work and, of these, 1 358 used electricity for power purposes. The corresponding totals in 1933, i.e. 5 years ago, were 2 126 and 1 336 respectively. At first sight it may seem surprising that upwards of 750 mines are without electrical equipment for power purposes, but the great majority are small mines, mainly on the fringes of certain of the coal-fields.

Under the Coal Mines Act every colliery is required to make a return of the number and horse-power of electric motors installed. When this return was first made in 1912, there were in use above-ground and below-ground at all mines under the Coal Mines Act motors totalling in round figures 511 000 h.p., of which 316 000 h.p. or

Table 2

	1912 Coal output, 273 000 000 tons		1937 Coal output, 240 400 000 tons	
	h.p.	%	h.p.	%
Above-ground:				
Winding	23 896	4·68	165 787	7·66
Haulage	23 755	4·65	86 670	4·00
Ventilation	30 895	6·0	129 073	5·96
Other purposes	115 543	22·60	628 820	29·10
Below-ground:				
Haulage	130 026	25·50	457 389	21·15
Pumping	144 318	28·30	427 084	19·75
Coal-cutting and Conveying ..	31 037	6·07	226 551	10·48
Other purposes	11 286	2·20	40 641	1·90
Total	510 756	100·0 %	2 162 015	100·0 %

61 % was installed below-ground. The corresponding total horse-power for 1937 was 2 162 000, of which 1 152 000 or 53 % was installed below-ground. The allocation for different purposes above- and below-ground is shown by Table 2.

The increase in the total horse-power recorded for 1937 over 1936 was 83 000, an increase substantially in excess of that recorded in any previous year. The total horse-power above-ground as well as below-ground now exceeds 1 000 000.

Before the year 1927 the allocation between direct current and 3-phase alternating current was not known, but in that year 80 % of the total horse-power installed was 3-phase alternating current. In 1937, i.e. 10 years later, the proportion of 3-phase alternating current was 84 %. That there should remain some 336 000 h.p. of direct-current motors in use is surprising. This figure has varied only very slightly during the last 10 years, a fact due no doubt to the serious outlay which conversion to alternating current would entail. Direct current has certain advantages for winding, but winding accounts for less than 8 % of the total electrical horse-power installed, a percentage far below the percentage of winding horse-power of all kinds to total horse-power of all kinds. For winding purposes as for ventilation, to which less than 6 % of the total horse-power of motors is allocated, the steam engine still retains its hold. Of the individual items in Table 2, the largest is 628 820 h.p. of motors used on the surface for " other purposes," that is other than winding, haulage, and ventilation. These miscellaneous other purposes include coal screening, cleaning, and conveying, to which 218 100 h.p. is allocated, surface haulage, surface air-compressors, and a considerable horse-power of motors driving machinery in colliery workshops.

(a) Haulage

Haulage by rope, either motor-driven or engine-driven, is practically the only method of haulage. That picturesque animal the pit pony, which has deserved well of its time and generation, is being slowly withdrawn from the mines. In 1913 there were 73 000 in use; in 1937 that number had fallen to 33 000, and it may be expected that in a few years the " pit pony," sometimes a horse 14 hands high, will have ceased his often very arduous labours.

Locomotive haulage can rarely be applied to advantage in a mine roadway not constructed for that method of haulage. Gradients, which frequently vary at short intervals in the same length of roadway, and also curve radii, and the dimensions of the roadway, not to mention the rail bed, impose conditions which are found to be too severe in practice. Although storage-battery locomotives have been used from time to time, there are very few at work to-day. Electric trolley locomotives are generally inapplicable. In one suitable instance in an open-light mine in Somerset consent was given by the Mines Department, but the project did not materialize. With the possible exception of pumping, electricity has been of no greater service to the mining engineer than in assisting to solve the problem of the haulage of heavy trains of coal below-ground. Otherwise than by modern electrically-driven haulage gear, it is difficult to see how the traffic problem in a large mine could be successfully and economically handled.

(b) Pumping

Historically, the first application of mechanical power was for unwatering the Cornish mines in the early 1700's. Pumping machinery has gone through a long process of development since that time, during which the driven machinery has literally been revolutionized and the driving and driven machinery have moved from the surface of the mine, first to insets in the side of the shaft for stage-pumping, then to the shaft bottom, and later, if required, long distances in-bye. Although there is a large number of 3-throw ram pumps of high efficiency in use, the greater part of the 427 084 h.p. of electric motors in present use for pumping is direct coupled to high-lift multi-stage centrifugal pumps, which are ideally suited for electric drive. The combination of an electric motor coupled direct to a centrifugal pump has solved an age-old problem very cheaply and conveniently, particularly in mines where the combination is met of heavy water feeders and great depths from the surface.

(c) Machine Mining

The growth of machine-mining, especially during recent years, has been very marked. In 1910, 16 million tons of coal, i.e. 5·7 % of the total output, was machine-cut, whereas in 1937, 27 years later, more than 137 million tons of coal, or 57 % of the total output, was machine-cut. Electricity and compressed air are rival sources of power for this purpose. The use of both is increasing, but electricity more rapidly. Of the 137 million tons of machine-cut coal in 1937 over 97 million tons, more than 70 % of the total, was cut by electricity; but it should be mentioned that in that same year more than 13 million tons of coal was won by the use of pneumatic picks, to which there is no electrical equivalent. This compares with 4 million tons in 1932. Compressed air is also used much more extensively than electricity for rock-drilling.

The use of mechanical conveyors underground has increased rapidly in recent years. In 1927 there were in use 2 856 conveyors and loaders; and 28 million tons, or 11·4 % of the total output, was mechanically conveyed for short distances at or near the coal-face. In 1937, 10 years later, there were 8 031 conveyors and loaders in use, of which 60 % was electrically-driven, and 123 million tons, 51 % of the total output, was mechanically conveyed. As more than one-half of the total output of coal in 1937 was machine-cut and machine-conveyed, it is obvious that coal-cutting and coal-conveying are progressing side by side. Their general applicability to thick as well as to thin seams of coal is now fully recognized.

(d) Lighting

According to the official returns there were in 1937 some 93 000 lamps connected to distribution mains below-ground. Of these, 46 % was used at shaft insets and sidings, 25 % on roadways, and the balance of 29 % in cabins, stables, and motor rooms. The number of lamps fed from distribution mains in use at the coal-face in 1937 was returned as 41. Altogether it appears from the returns that, having regard to the importance of good lighting in manual labour of all kinds, both the number of lamps in use and the rate of growth of mains-lighting below-ground are surprisingly low.

Apart from mains-lighting there were in use at or near the coal-face 1 850 self-contained lighting units, each consisting of a magneto-generator driven by a small compressed-air turbine.

The return of electric hand safety lamps in use is of interest. In 1908, 30 years ago, fewer than 10 000 electric safety lamps were being used, in conjunction with 750 000 oil safety lamps. In 1937 there were 462 402 electric safety lamps and 177 048 oil safety lamps in use. The diminished total number of lamps is due to the fact that the output of coal is now some 20 or 30 million tons per annum less than it was in 1908, and diminished output, together with mechanized mining, is reflected in fewer miners and therefore fewer miners' lamps. The electric safety lamp has so many inherent advantages that the successful development of a gas-testing attachment, towards which many promising efforts have been and are being made, would see almost the last of the Davy lamp, which, with its numerous improvements, has served the mining community superlatively well for 125 years since its first invention. Though totally irrelevant to our subject, it may be recalled that the inventor of the Davy lamp in the course of his experiments as a boy produced an explosion in the garret of his employer, a Penzance surgeon. "Was there ever so idle a dog?" asked the surgeon. "He will blow us all into the air." Amongst the hierarchy of false prophets the Cornish surgeon must occupy a very distinguished position.

(3) SAFETY REGULATIONS

In 1902 a Departmental Committee of six members was appointed by the then Home Secretary, "to inquire into the use of electricity in coal and metalliferous mines and the dangers attending it, and to report what measures should be adopted in the interests of safety by the establishment of Special Rules or otherwise." The Committee heard evidence and duly reported, including in their recommendations a code of Special Rules. This code was ultimately adopted by the Home Office (then in control of the administration of mining legislation), and in due course the first code of Regulations governing the use of electricity in mines was made applicable in the year 1905. There were at that time no Regulations governing the use of electricity in factories, the first code of Factory Regulations not being made applicable until 1908, 3 years later.

(a) The Electricity Regulations of 1913

In 1909 the Home Office appointed a second Committee, this time of three members, "to inquire into the working of the existing Special Rules for the use of Electricity in Mines, and to consider whether any, and if so what, amendments are required." This Committee also heard evidence and reported, including in their recommendations a revised code of Special Rules based upon experience obtained since 1905, but limited in their application to installations below-ground, except in so far as apparatus on the surface might directly affect the safety of persons below-ground. This Committee's recommendations were also in due course adopted by the Home Office and revised Rules were established at the collieries in 1913 as "General Regulations" under the Coal Mines Act 1911, which in the interval since the appointment of the Committee had been placed upon the statute book. An Explanatory Memorandum was published with the new Regulations in the early part of 1914. With minor additions and alterations the Regulations established in 1913 have held the field until the present day, but in order to keep abreast of technical developments the explanatory memorandum has been revised and re-issued from time to time. The last revision was made in 1937.

The Committee of 1909 stated in their report that their endeavour had been "to set out clearly the conditions to be fulfilled, leaving it to the manufacturers and engineers to determine the exact way in which to meet those conditions by proper construction." The fact that a code of Regulations established 25 years ago remains substantially unaltered is evidence that the conditions had been carefully studied and the Regulations reasonably well drawn. Leakage protection was regarded by the Committee as having a special field below-ground in coal mines. Its use was advocated accordingly in the memorandum which accompanied the new Regulations, but at the time the Memorandum was prepared this conception was some way in advance of mining experience and practice. Some years of education and the development of suitable apparatus were needed before sensitive leakage protection became, as it now is, a commonplace provision. Altogether, taking all the factors into consideration, including developments that were beneath the horizon at the time, the Regulations have assisted to maintain the accident rate due to electricity at an encouragingly low level during practically the whole of the period under review.

The main requirements of the new Regulations were first the compulsory use of armoured cables, secondly insistence upon an effective earth connection for all metallic outer coverings throughout the installation *via* the armouring of the cables, and, finally, the flame-proof enclosure of apparatus in any part of any mine in which firedamp, though not normally present, might, nevertheless, occur in quantity sufficient to be indicative of danger. Though some of the requirements of the Regulations as originally drafted were stated in terms more comprehensive than precise, it is thought that all ambiguities have since been removed. Administratively the new Regulations conferred upon Divisional Inspectors of Mines greater power of objection to the introduction, or continued use, of electricity in places where its use might be held to introduce the possibility of danger. The details and implications of this extension of official responsibility are well known to those concerned and need not be enlarged upon.

(b) Additional Regulations

In 1934 the Mines Department established General Regulations applicable to electric lighting in those mines in which approved safety lamps are required by the Coal Mines Act. A point of general interest in these Regulations is that they require for the first time the use of officially approved electrical equipment under certain defined conditions, though for lighting only, thus following a practice long-established in respect of safety lamps and the use of explosives.

The voluntary submission by manufacturers of signalling bells and relays to official test has been in operation for many years, following the explosion at Senghenydd Colliery in 1913 to which reference has been made. A further code of Regulations has recently made compulsory the use of officially-approved signalling bells and relays, save for shaft signalling, and officially-approved telephones in any mine, or any part of any mine, in which approved safety lamps are required by the Coal Mines Act. Reference has been made to the design and construction of intrinsically safe circuits of small power and low voltage for signalling. It is sufficient to recall that by limiting the current, voltage, and self-induction in the circuit it is possible to ensure that any sparking associated with signalling instruments and apparatus, or with circuit wires connected thereto, shall be incapable of igniting fire-damp under normal working conditions.

(c) Accidents in Coal Mines due to Electricity

As complete statistical data is available in the published reports of the Mines Department, this aspect of electricity in mines may be summarized very briefly. To provide a scale or "yard-stick" it is necessary to consider electrical accidents in relation to all accidents in coal mines.

During the 10 years from the end of 1926 to the end of 1936 (the last year for which full statistics are available) 8 656 lives were lost in consequence of accidents below-ground in mines working under the Coal Mines Act. Of this total electricity was responsible for 224 deaths in all, whether due to shock, fire, or the ignition of fire-damp. Over a period of 10 years, therefore, electricity has been responsible for $2\frac{1}{2}$ % of the total number of fatalities. Of the total number of persons injured, and absent from work for at least 3 days in consequence of injury, the proportion is much less, namely 0·027 %.

In his Annual Report for 1937 the Electrical Inspector of Mines tabulates all accidents due to the use of electricity above-ground and below-ground during the 10 years 1928–1937 inclusive. The information contained in Table 3 is abstracted from that Report. The total number of persons employed on the surface and underground would be 760 000 very closely, 160 000 on the surface and 600 000 underground, not all of whom are exposed to the risk of electrical accident. Of the 79 fatal electric shock accidents 17 occurred on the surface and 62 below-ground. Of the 21 ignitions of fire-damp, by far the most serious was that at Wharncliffe Woodmoor Colliery, near Barnsley, on the 6th August, 1936, caused by sparking at the (uncovered) commutator or starting switch of a loader motor, whereby 58 lives were lost—more than one-third of the total number in Table 3. Of the remainder, 33 persons in all were killed in two explosions caused by unsafe signalling bells, 27 by one accident in 1932 and 6 by a second in 1933. The balance of 64 deaths is spread over 18 separate ignitions. Fires below-ground caused by damage to, or the failure of, electrical apparatus were 3 in number and caused 7 deaths. Fires due to other agencies in the same period caused 17 deaths.

Table 3

Nature of accident	No. of fatal accidents 1928–1937	No. of persons killed
Electric shock	79	79
Ignition of fire-damp	21	155
Fire below-ground	3	7
Other causes	1	1
Total	104	242

From the above information it is apparent that over 10 years the average number of electrical accidents causing loss of life is 10·4 per annum, and the average number of deaths 24·2 per annum. Actually during the first half of the period under review there were 50 accidents for which electricity was responsible, causing 105 deaths, during the second half 54 accidents, causing 137 deaths. If it were not for the increase of over 300 000 h.p. of electric motors in use, and a considerable increase therefore in the number of miners subject to the risk of electrical accident, the increased death rate would be more disquieting than it is.

(d) Maintenance and Design in Relation to Accidents

In considering the problem of how to make electrical equipment safe under mining conditions, it should be remembered that the miner is accustomed to rough and even violent methods of working, to robust, not to say clumsy appliances, and to taking risks from sources outside his own control as a matter of course. Moreover, both the equipment and the men are so scattered and relatively inaccessible that supervision as understood and practised on the surface is impossible, all of which goes to suggest that the designer of colliery electrical equipment should aim at the production of plant and apparatus which is proof against easy derangement and irresponsible interference. Bearing in mind the conditions under which repairs may have to be carried out below-ground, it is a great practical convenience when component parts of plant and apparatus subject to wear or other deterioration are made capable of easy removal so that they can be replaced by "spares" without extensive dismantling. Maintenance, properly applied, is the best means of avoiding accident, and even here the designer can help the user. If electrical and mechanical parts subject to renewal are difficult of access preventive maintenance is likely to be neglected. Proper repairs, as distinct from replacement of parts, are often impossible under underground conditions and it materially assists towards good maintenance when this fact is recognized by the designer.

The design of electrical machinery and cables for underground use has, however, improved so much in recent years that as old plant is replaced by new, safety is becoming more and more dependent upon a high standard of maintenance, allied of course to proper use, as opposed to misuse, of the plant.

(4) A FORECAST OF FUTURE DEVELOPMENT

It has been stated that the systematic application of labour-saving machinery had become an economic necessity 10 years ago, hence the rapid growth in the use of coal-cutting and coal-conveying machinery in more recent years. The number of coal-face conveyors in use has more than doubled, and the output of coal conveyed has quadrupled in the last 7 years. But as 43 % of the coal raised is still hand-won, and 49 % remains hand- or pony-conveyed for the whole or some part of its journey to the shaft bottom, there is clearly scope for the extended use of electricity below-ground. Though mechanized mining introduces difficulties which necessitate changes in the layout and system of working, and there are many small mines unlikely ever to be mechanized, probably some near approach to 90 % of the total output of coal will eventually be machine-cut and then machine-conveyed, or otherwise mechanically transported, from the coal-face to the surface.*

(a) The Field for Future Development

That is one aspect of the field for future development. Looking at the question broadly, there is, so far as the author is aware, no completely up-to-date information available, but an estimate made in 1933 gave 3 million horsepower† of driving machinery of all kinds, steam, electric and compressed air, installed in the coal mines of Great Britain. Allowing for the displacement of hand labour by the extended use of mechanical power since 1933, it is probable that there is now some near approach to 3¼ million horse-power, and it follows from data given in Table 2 that about one-third of the engine capacity in the mines of Great Britain, rather more than 1 000 000 h.p., still remains non-electric. Such estimates are naturally given with reserve, and will be so received; but there are mines still mainly dependent upon steam engines, and others which distribute compressed-air from the surface a mile or more in-bye, where electricity might well be used to transmit power to air compressors stationed, if necessary, some distance back from the coal-face. In each case there appears to be room for the extended use of electricity. Looking at the field for extension from another standpoint, it might reasonably be argued that complete electrification is actually within sight. It may be remembered that the horse-power of motors installed during 1937 amounted in the aggregate to 83 000 h.p., and that the rate of increase is on the upward grade. If that be so, and there remains only 1 000 000 h.p. of engine power yet to be converted to electric drive, 10 years might well see the last colliery winding-engine removed with due ceremony to South Kensington Museum. That might well be a satisfying reflection, did not the author pause to remember that in a certain distribution area a census of engine power was prepared but in a very short time the total horse-power so carefully recorded was far outstripped by the horse-power of electric motors installed. The parallel is not by any means exact, but to those who prefer an indefinite to a definite objective the recollection is at least an encouragement.

The partial electrification of a colliery, leaving out the winding engines and the larger surface steam engines such as the fan engine, involving only partial shutting down of the colliery boiler-plant, is sometimes only moderately successful. Partial electrifications are, as a rule, greatly improved by a complete change-over. For reasons which are readily understandable the winding engines are usually the last item to be converted, but they are also the largest steam users and are often wasteful. The grid transmission system has made electricity from the public supply available in all coal-fields; it has also made possible the use of electricity for winding purposes in many places where formerly such use was impracticable. Mainly for this last reason the author is of opinion that there will be an increase in the number of all-electric collieries in the near future. The first of these, the Britannia Colliery in Glamorganshire, dates from 1910, so that they are in no sense a novelty. Individual collieries of this character in the Midland coal-field have as much as 10 000 h.p. of motors installed.

(b) Privately-Owned Generating Plant versus Public Supply

Mention of the availability of current from the public supply raises the debatable question of the source of power supply at a colliery. The reasons underlying the mining engineer's point of view are well understood and, in part at least, appreciated. The mining engineer's point of view was given in evidence before the Royal Commission on the coal industry in 1925, and, so far as can be judged, it remains substantially unaltered. It was then said that "unless power companies can supply current at prices very largely below those now in operation, the major proportion of the collieries is correct in continuing to produce power either from exhaust steam or by waste heat from other sources or by generating plant using low-cost fuel."* That statement of policy was not made in respect of the larger colliery establishments alone, it referred to the "major proportion of the collieries," and implied support of the policy of continuing to use private generating plant for colliery purposes. The question raised is one upon which no general conclusion can be given, for each case requires consideration on its merits; but, even then, electrical and mining engineers often find themselves at variance.

A mining engineer justifying the existence of a private generating plant such as is seen "at the major proportion of the collieries," has the argument of a plant-in-being to support his view, coupled with the use of fuel, a sale for which cannot always, or readily, be found. In a few cases waste heat from one source or another is available. On the other hand, to set against these substantial arguments there is the fact that the generating cost per unit is often a good deal higher than is realized; *saleable* coal in varying quantity is often used.

An electrical engineer, an emissary of the power supply authority, subjecting a colliery generating-plant such as is envisaged above to friendly scrutiny, may well feel that from the point of view of efficient power generation he is contemplating an anachronism. But he, too, may not have the whole situation in mind. He may not appreciate that a saving of 50 or even 100 % in the cost of power may mean no more than a very small saving per ton in the cost of coal won.* For this reason many colliery undertakings hesitate long before deciding to change a well-established custom by purchasing current from outside, but the point at issue is often determined by a narrow comparison of estimated rather than actual costs, leaving out of account the incidental advantages which go with a supply of power from an outside source. Such advantages are the ease and quickness with which new machinery can be introduced without added capital outlay; the greater reliability, in general, of the outside supply (provided, of course, that due precautions are taken; for example connection to more than one feeder); and lastly the convenience of having current "on tap," so that power is available at all hours, including week-ends and holidays, without the necessity of employing at these odd times more than the minimum of labour. It is difficult to give these facilities a cash value, but each of them tends towards cheaper production, so that taking everything into account it may reasonably be anticipated that the near future will show a growing tendency towards the purchase of current from outside sources. There is, nevertheless, still some way to go, for mining engineers are rightly reluctant to depend upon outside supplies for the two most important of all colliery services, namely winding and ventilation. Safety is intimately involved, and mining engineers think instinctively in terms of safety. Progress must therefore be slow, but if electrical engineers fulfil conscientiously their part of the bargain there should be no fear of retrogression.

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* In the North Staffordshire Coalfield already 90 % of the coal won is mechanically conveyed; in the Midlands 75 %; and in Scotland 73 %.

† B. Welbourn: *Journal I.E.E.*, 1934, vol. 74, p. 52.

* *Transactions of the Institution of Mining Engineers*, 1926, vol. 70, p. 119.

(c) An Opportunity for Co-operation

In the recently developed South Yorkshire and Nottinghamshire coalfields some of the larger collieries are interconnected by a system of transmission mains, an example of co-operative working of which there are not too many in industry. Reference has been made to the use of the grid transmission-system in relation to the extended use of electricity in mines. It is not straining the argument to describe the national grid as a co-operative enterprise. Its function is to co-ordinate the generation of electricity so as to ensure the lowest possible cost of production, and to supply current "in bulk" to public electricity-supply authorities. These latter are thus enabled to distribute in rural areas, including the coalfields, power which has been generated cheaply near the great centres of population. The grid transmission-system may be regarded as a co-operative link between urban and rural areas for the supply in the latter areas of cheaper current than would otherwise be economically possible. The grid transmission-system is controlled by the Central Electricity Board, which also controls, as "selected stations" under the 1926 Electricity Act, the more efficient and more economical generating stations of the public electricity-supply undertakings. In the year 1937 these undertakings burnt 14¾ million tons of coal in producing current. The coal industry on the other hand is a large power user. In 1937 some 12 million tons of coal were burnt under colliery boilers for generating power, which is only 2½ million tons less than the amount of coal used to generate the whole of the current used for general supply purposes throughout the country. It has been estimated that if the whole of the collieries were electrified the annual consumption of current would be of the order of 5 500 million units,* almost exactly one-quarter of the total amount of current generated in the public electricity-supply stations in 1937, namely 22 011 million units. It appears to a disinterested onlooker that, between two well-organized industries, one almost solely dependent upon the other for its raw material, namely coal, and the producer of the raw material potentially the largest individual user of the finished product, namely electricity, there exists an opportunity for some degree of co-operation which, while opposed to no outside interest, might well benefit materially both the parties concerned and, through them, provide cheaper power for those industries, very large in number, which are almost of necessity dependent for power upon the public supply.

It may be said in favour of the policy adumbrated that local examples of co-operative working between collieries and power-supply authorities do exist. Electrification of a particular colliery has sometimes been assisted by the purchase by the electricity supply authority of coal from that colliery. In other cases generating plant is run at full load at times when the colliery demand is low, the surplus current being purchased by the supply authority at a cheap rate for distribution to its ordinary consumers. A wider measure of co-operation might take this form: The electricity supply authorities' stations are usually designed for the use of fuel of moderate calorific value and, broadly speaking, of inferior grade. In these days of quotas and controlled output it does not seem extravagant to suggest that a small but properly constituted Fuel and Power Board might be set up in each coalfield to correlate fuel and power. The function of such a Board on its executive side would be so to control production as to provide at fixed cost the approximate quantity of the kind of fuel needed for power generation. The advantage to the collieries would be a market for low-grade fuel, coupled with power "on tap" at schedule rates for all collieries in the coalfield. The wider provision of cheap and unlimited current would facilitate the use of electricity for all colliery purposes, and directly improve the economics of the coal industry by materially assisting mechanical mining. The advantage to the electricity-supply industry would be fuel in sufficient quantity and of known quality, much less subject to fortuitous and rapid increase of cost than now, coupled with considerable increase of the colliery load. In brief, an arrangement by which each industry would obtain from the other favourable terms and, so far as each affects the other, more stable conditions. Co-operation by omnibus agreement on lines such as these is envisaged as a possible future development.

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* An average saving of ½d. per ton on 240 million tons of coal raised would be less than ¼ % saving in the pit-head price of the coal, but would, nevertheless, be a saving to the coal industry of more than £500 000 per annum.

* B. Welbourn: *Journal I.E.E.*, 1934, vol. 74, p. 52.

(d) Electric Lighting from the Mains Below-ground

On the subject of general lighting and coal-face lighting from the power-distribution system, progress has, so far, been disappointingly slow. Though some main haulage roads are adequately lighted, the author is aware of few collieries where lighting from the mains is carried far into the mine, even in places where current is already available. In spite of the fact that the researches of Prof. W. M. Thornton and others have seemed at times to offer the possibility of early development, underground electric lighting has not kept pace with development in other directions. In view of the rapidly extended use of coal-conveying machinery in-bye, this fact is surprising, for such machinery requires good general lighting. At the coal-face itself there is the difficulty of carrying forward the lamps, cables, and control apparatus as the face advances, and the recent improvement in illumination obtainable from oil and electric safety lamps has no doubt had some influence, but in the numerous auxiliary haulage roads there appears to be a clear opportunity. Speaking of underground lighting from the mains in his Annual Report for 1936, the Secretary for Mines remarks that " mains lighting " shows " disappointingly little increase." He goes on to say, " there are strong grounds for a much greater use of this method of lighting in and around pit bottoms and landings, and within a reasonable distance from the pit bottom along main haulage roads which are intake airways. In some mines there is good reason for keeping it away from the coal-face area and it is not suggested that risks should be taken, but it is difficult indeed to see any adequate reason why there should not be more mains lighting along haulage roads in mines where electric power is already used at the coal-face for coal-cutting, conveying, and other purposes." It seems clear that there is ample room for the extension of mains lighting in suitable places, and altogether an opportunity is presented to those immediately concerned for the general improvement of underground lighting.

(e) Summary of Forecast

Summarizing this brief forecast of possible future developments, it is considered:

(1) That there remains more than 1 million horse-power of driven machinery still to be electrified.

(2) That the influence of the grid transmission-system will tend to increase the number of all-electric collieries, and generally tend towards the purchase of current from outside as opposed to the use of private generating plant.

(3) That there exists an opportunity for some measure of co-operation between the coal and electricity-supply industries in the common interest, of which advantage will, it is hoped, be taken.

(4) That the use of electricity below-ground has still a wide field before it in connection with mechanized mining.

(5) And, finally, that electric lighting from the mains will largely extend along main roads and auxiliary haulage roads clear of the coal-face.

(f) The Ultimate Objective

With much that is encouraging there is one aspect of electricity in mines, namely the still persisting mistrust of the miners, which it would be unwise to ignore and which it would be wise, if possible, to remove. A representative mining authority[*] discussing a recent increase in the number of fatalities in mines,[†] wrote: " Modern mechanical methods do not improve things generally for the miner. . . . Electricity certainly adds to the danger of a task which in all conscience was sufficiently testing before the advent of these things. There is much heart-searching among miners on this question of electrically-driven machines in pits. . . . That question will be reported on shortly by the Royal Commission which has been sitting for over 2 years." There, in the circumstances, this last aspect of the matter must be left.

The author feels encouraged by these remarks to offer the following for consideration as a parting thought: In a book on the subject of " Visits to Remarkable Places " published in 1860, the writer appears to have included in his travels a visit to the northern coalfield.[‡] The impression made upon him by the colliery establishments of the time, when all the mechanical power in use was provided at the surface of the mine, was as follows:—

> " Wherever reared themselves those tall engine-houses, there also towered aloft two vapoury columns, one of black smoke, and one, near it, of white steam. These neighbouring columns, like the ghosts of Ossa, slanted themselves in the wind and wavered spectre-like in the air, each like some demon with a pale spirit in his keeping whom he was compelling to enormous labours, and such noises filled them as served to confirm the belief of it. Some of these engines were groaning, some puffing, some making the most unearthly sighings and yawnings, as if the very Gouls and Afrits of the Eastern stories were set to stupendous labours, and were doing them in despair."

It is not suggested that the removal of electricity from the pits would entail a return to engines at the surface, " groaning and puffing, some making the most unearthly sighings and yawnings," for compressed air is for most purposes very adequate and steam engineering practice is less noisy than it used to be, but there is in the miners' hostility to the use of electricity a challenge to electrical engineers. Hostility, if not well-founded, can be patiently removed. A famous Scotsman, Robert Louis Stevenson, has this to say on the subject of offering advice: " It is never a thankful office to offer advice. . . . We are fired with anger against those who make themselves the spokesmen of plain obligations." Yet, in spite of direct discouragement from high authority, the author would venture to remind those directly concerned with the distribution and use of electricity below-ground that underground workmen are still, for the most part, completely ignorant of electricity. It represents to them a risk which they are unable to measure by ordinary standards. The colliery electrical engineer has therefore an unusual opportunity. He will perhaps decide that his work, with its high degree of responsibility, is not to be ambled through in the easiest and most convenient way, but that it calls on the other hand for close attention to many points of practical detail, and, added to that, unremitting vigilance. The task of alleviating the miners' mistrust rests more clearly upon him than upon any other colliery official.

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[*] John Lawson, M.P., in *The Spectator* of 19th August, 1938, page 291.

[†] The total number of fatalities in the 3 years 1935, 1936, 1937, was 763, 726, and 774 respectively.

[‡] See *Proceedings of the Association of Mining Electrical Engineers*, 1913, vol. 4, p. 555.

CONCLUSION.

The author is aware of the inadequacy of this retrospect over so long a period as 30 years, during which mining electrical plant has changed almost out of recognition, but he feels, nevertheless, that a paper primarily historical and statistical, and even mildly psychological, may be a useful background in considering the field that exists for future development.

ACKNOWLEDGMENT

The author wishes to thank Mr. J. A. B. Horsley, H.M. Electrical Inspector of Mines, for invaluable advice during the preparation of this paper and for much statistical information.

POSTSCRIPT

(*Received 25th October*, 1938.)

Since this paper was written, the Report on the explosion at Markham Colliery, Derbyshire, on the 10th May, 1938, whereby 79 men lost their lives, has been issued. The Report states that the probable originating cause was the ignition of a cloud of coal dust by open sparking resulting from the destruction of a cable-joint box by the piling up of a set of runaway tubs in the roadway containing the cable, the coal dust which ignited having shot out from the tubs.

The Commissioner who conducted the inquiry reached his conclusion by a process of exhaustive reasoning rather than from positive evidence; but, nevertheless, the verdict that a damaged cable-joint box caused a major colliery disaster stands, and electricity must bear its due share of responsibility accordingly. Of the remedies proposed, two only have reference to electricity. In the Commissioner's own words:—

"(1) The joint boxes might very well be made with more sturdy covers, possibly of some material less brittle than cast iron.

"(2) Joint boxes should be placed in recesses or be protected by very stout barriers."

On the subject of stone-dusting the Commissioner remarks:

"The explosion in this mine would I am convinced have been made more violent and much more extensive but for the stone-dust which had been applied along its roads."

DISCUSSION BEFORE THE INSTITUTION, 1ST DECEMBER, 1938

Mr. W. B. Woodhouse: The author gives rather scant credit to the work done by power companies when in Section (4)(*a*) he says: "The grid transmission system has made electricity from the public supply available in all coalfields." I would remind him that in every coalfield in this country a supply of electricity was made available through the activities of the various electric power companies. The grid transmission system also was made possible by those companies.

With regard to the cause of explosions, it is so easy to test electrical circuits and apparatus that whenever there is an explosion in a mine where electricity is used there is a tendency to say first of all "Let us test the electrical apparatus and see whether that was the cause." This facility tends by association of ideas to throw suspicion on electricity, quite without justification in many cases. There are many other causes about which little is known; for example, the author refers to the improvement in the standard of safety which has resulted from stone dusting, but recent experience has shown that this is not always the full safeguard that it was thought to be.

As the result of recent legislation the coal mining industry has been put in the position of a quasi monopoly, and has become a public utility akin in nature to gas and electricity. Its kinship is the more apparent because people prefer more and more to use electricity rather than raw coal: consequently the coal industry must co-operate with the electricity supply interests. A considerable measure of co-operation already exists in the use of waste heat and special fuels. For example, my company in Yorkshire has been using coke-oven gas for 20 years for producing electricity, and has made other joint working arrangements. The gas industry is also co-operating by taking coke-oven gas from collieries in many places. The economic advantages of such co-operation will increase because of dearer coal and of improved efficiency of power production. A hundred years ago, the pithead price of coal was 3s. 6d. a ton. When the power companies came into being, about the beginning of this century, it was about 8s. To-day it is about twice that figure, and thermal efficiency is correspondingly more important.

The phrase "unsaleable coal" is to-day a misnomer; any low-grade coal which can be used at the colliery can be consumed more efficiently in an electric power station operated by those whose principal business is the economic production of power. These reasons justify the fullest co-operation between the industries.

Prof. W. M. Thornton: Engineers have been able to see and judge for themselves most of the striking advances that have been made in the applications of electricity during the last 40 years, but few have had the opportunity of seeing the remarkable change that has taken place, deep in the earth, in the use of electricity in coal mining.

There can be no doubt that for efficiency and flexibility of application electricity as a medium is unequalled, but it entails certain risks. The author had for many years the difficult task of observing these risks and guarding the lives of the workers by regulations for the safe use of electricity in coal mines. As he has said, the work of the 1913 Committee was so well done that now only small modifications of the regulations are from time to time required.

With over a million horse-power in use below-ground and another million on the surface, with coal-cutting machinery, drills, conveyors, and haulages with trailing cables and portable switches in continual change of position, the fatal accidents, including explosions, due to the use of electricity are now no more than 2½ % of the whole. The remaining 97½ % are mostly due to mechanical causes such as "falls of roof and side."

To give an example of how rapid the early progress was, at the first coal mine that I went down, in Somerset in 1896, the pumping was done by a Newcomen engine, 100 years old and the last of its kind; the ventilation was by means of a huge fire at the shaft bottom; there was no gas, but the fine coal-dust was smothering. Yet a few years later I was referee for a complete 3-phase installation at Axwell Park Colliery in Co. Durham, with a Siemens–Ilgner winder, centrifugal pumps, and most of the modern equipments (but not, I think, armoured cables; they came later). I saw elsewhere in Durham, early in the century, 3-phase 500-volt motors with bare terminals 1¼ in. apart, home-made fuse-boxes, and other offences which have long since gone into oblivion, largely owing to the careful inspection and advice of Mr. Nelson, Mr. Horsley, and their colleagues, with the collaboration of pioneers of safety in mines such as the late H. W. Clothier, and the consulting engineers.

Thirty years ago practically nothing was known about the electrical ignition of mine gases or coal dust. Each of the great explosions to which the author refers led to marked and permanent advances in safety. The West Stanley, in 1908, started systematic researches on ignition. The Hulton explosion, in 1910, though inconclusive, emphasized the need for the constant inspection and maintenance of underground electrical plant, and increased the responsibilities of the colliery electrician, who is only now receiving his proper status. The Senghenydd explosion, in 1913, led to a great improvement in safe methods of signalling underground; but the Markham explosion, of May, 1938, holds a lesson the significance of which has still to be realized. The explosion was the result of an ignition of dust by an electric flash. The conditions for this to occur were worked out by me and the late E. Bowden* in 1910, and in 1913 the influence of the presence of fire-damp on such explosions was established in a paper which I read before the British Association.† In these days of armoured cables and protective gear the striking of an open electric arc underground must be a very rare occurrence. That it should take place in the midst of a dense cloud of inflammable dust is, in a well-stone-dusted mine, rarer still. But both of these conditions occurred together at the Markham pit, where every known measure was taken to ensure safety. The ventilation was good, but if ½ % of gas had been present the risk of dust ignition would have been largely increased, and with 1½ % of gas every such ignition would result in a violent explosion. It is this very rare combination of events that was, I suggest, the cause of the Markham explosion—a little gas, dust, and an arc together. Now it is required by the Regulations that electricity must be cut off when there is 1¼ % of gas present in the air. With a flame lamp it is very difficult, but just possible, to observe so small a percentage, yet testing by a flame lamp is at present the only method allowed by the Coal Mines Act (1911) as a statutory test. This appears to be the lowest limit that a flame lamp can ever detect, and there is a growing need for an electrical gas-detector capable of giving a positive indication of fire-damp at 1¼ % or even less. If my interpretation of the reason why a dust ignition developed into a major explosion in a stone-dusted mine is correct, this need is emphasized.

As to the future of electricity in coal mines, the position seems to be that of a group of men working on a difficult job, some with old-fashioned hand tools, others with the most modern machines. It is inevitable that the latter should displace the former wherever this is economical or possible. There is undoubtedly great scope for advance, and the author has in his forecast shown very clearly how it may be made.

Mr. J. A. B. Horsley: It may not be generally known that more than half the number of deaths below ground are caused by falls of ground, that nearly one-quarter are associated with haulage, and that deaths due to the ignition of fire-damp during the last 10 years represent about one-tenth of the total number. It is not surprising, however, that the coal miner regards explosion as the dominant risk, because there is always the possibility that a large number of lives may be lost in one accident.

During the 19 years from 1919 to 1937 inclusive there were altogether 1 174 ignitions of fire-damp from which death or other personal injury resulted. Of this total number, 910 were caused by the use of open lights, mostly in naked-light pits. Of the remainder, 82 were due to the use of explosives; 48 to the use of electricity, including electricity for signalling; 41 to matches, 28 to damaged or defective safety-lamps; and 9 to spontaneous combustion or to fire otherwise caused; leaving a balance of 56 due to other or unascertainable causes. Electricity accounted, therefore, for 4 % of the total, if ignitions due to open lights are included, or for 17½ % of the reduced total if ignitions due to open lights are excluded. It is interesting to divide that period of 19 years into two overlapping periods of 10 years each, and to see what number of ignitions of fire-damp were due to electricity in those periods. In the first period of 10 years there were 22 ignitions of fire-damp, all in association with the use of electricity for power. In the second 10 years there were 32 ignitions, which included two due to the use of unsafe signalling bells. These two ignitions accounted for 33 out of 155 deaths in that period from explosions due to electricity.

Explosions usually originate at or near to the coal face, and it is germane, therefore, to mention that at the beginning of that period, in 1919, 17 million tons of coal were cut by electrical machines, whereas at the end of that period, in 1937, the quantity of coal cut by electrical coal-cutting machines had risen to 97 million tons.

Perhaps the most interesting technical advances during the last 10–15 years have been (i) the application of core-balance leakage protection to underground circuits; (ii) the use of flexible cables with a screen of copper wires, or, in suitable cases, a flexible armouring of stranded steel wires for the service of coal-face machinery such as coal-cutting machines and conveyors; and (iii) the adoption of remote control for coal-face machinery, which as it is applied involves the direct switching of the load upon the line.

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* *Transactions of the Institution of Mining Engineers*, 1910, vol. 39, pt. 2, p. 1.
† *Colliery Guardian*, 13th Sept., 1913.

Mr. B. L. Metcalf: The paper raises again the issue of bulk supply versus power generation. The author says that the grid transmission system has made electricity from the public supply available in all coalfields; it has also made possible the use of electricity for winding purposes in many places where formerly such use was impracticable. These statements need clarifying in order to provide an explanation of why such a tremendous field of power remains to be tapped by the electricity supply industry.

The author estimates that 1 000 000 h.p. of colliery plant still remains to be electrified, and states that the total annual consumption of electricity if the whole of the collieries were electrified would be 5 500 million units. According to the 1930 census of production, 2 036 million units were generated in colliery power plant and 643 million units were purchased from supply authorities, making a total of 2 679 million units. The increase in the horse-power of motors installed from 1930 to 1937 was 368 000, and assuming 1 500 units per horse-power per annum (the average for the 1930 census of production) the figure of 2 679 million units is increased to 3 231 million units. A further increase of $\frac{1}{2}$ million h.p. would bring the total units up to 4 731 million, which indicates that the figure given by the author is a little on the high side. Horse-power is an unsatisfactory basis for estimating the possibilities of future development, as the horse-power quoted may either be that of a large motor driving a compressor on the surface which feeds compressed-air cutters and conveyors underground, or that of the aggregate of a number of small electric motors driving cutters and conveyors. Both the horse-power and the units will be bigger with the compressed-air scheme, owing to the greater efficiency of all-electric drive and the transmission of electricity as compared with the transmission of compressed air.

With regard to the availability of public supply, the crux of the matter is, of course, the cost, and a further point is the large number of retail distributors whose areas do not necessarily coincide with the geographical distribution of collieries or even with the area in which are found the pits belonging to one particular colliery. The North-East Coast coalfield benefits greatly from the fact that it is all supplied by one electric supply company.

Another point referred to in the paper is the question of the possibility of electrifying winders. The a.c. winder is now recognized as a comparatively cheap, serviceable, and robust installation, particularly with the latest improvements in dynamic braking to take care of unbalanced duties and to save wear on mechanical brakes or energy losses due to reverse-current braking. It is also safer than a steam winder owing to the ease with which the power is cut off and the usually lower winding speeds, which make it easier to comply with the new regulations for over-wind protection. In spite of this, however, the increase in winder electrification is exceedingly slow. One reason is no doubt the partial electrification to which the author refers, and the fact that the generating capacity at the average colliery would be insufficient to take care of the peaks associated with a.c. winders, even if it were sufficient to take care of the r.m.s. rating. Another difficulty is that the power plant at a colliery frequently consists of a mixed-pressure turbine taking the exhaust steam from the winders, so that if the winders are electrified high-pressure turbines must be substituted for the old mixed-pressure sets.

The author says that partial electrifications are, as a rule, greatly improved by a complete change-over, and he mentions the advantages to be obtained from public supply. I agree in general that it is the business of the power companies to supply power and of the collieries to produce coal, but the matter is not quite so simple as that. Such a view overlooks the question of the disposal of low-grade fuel—fuel on which it is not worth paying cartage but which is good enough to burn on the colliery boilers. The ideal condition for a colliery is that in which it is burning all the fuel it cannot sell and no more. (This quantity of fuel does not necessarily correspond to the electrical requirements of the colliery, but fluctuates according to market demand.) If the quantity burned is too much a surplus of electricity can be generated, but there is no outside market for this valuable by-product, except in one or two isolated cases. (The disposal of surplus power is also a problem with steelworks.) If the quantity is too small, the colliery is faced with burning saleable fuel or taking partial supply from the power company, probably at an exorbitant rate. These conditions hamper also the electrical development of collieries, which do not like to scrap their own generating plant and go over to the power company for all their supply; and physical conditions at the colliery may rule out the expansion of their own generating plant. These remarks deal chiefly with average collieries. A certain number of large colliery groups are able to maintain large efficiently-run power stations, take care of a number of a.c. winders on their system, and do their complete electrification themselves.

To deal with the problems outlined above, I think some kind of Fuel and Power Board would be excellent, as the author suggests, and I should like him to explain his ideas in greater detail. Would it be possible for a power company to take over colliery generating stations and run them for the collieries, burning the waste fuel on the spot and making up the deficiency from their central power station without appreciably increasing the cost of electricity to the colliery? The terms under which this change in management might take place could be assessed by the Fuel and Power Board. The power companies might then find that it paid them to take power from their own colliery generating stations instead of looking on these as competitors as they do now.

Regarding the use of electricity underground, the author rightly stresses that safety is becoming more and more dependent on maintenance. Mr. Horsley put it more broadly still in his evidence before the Royal Commission on Safety in Mines when he said, "the only effective solution is closer supervision not only of the plant but of the user of the plant." One of the tasks to which the Association of Mining Electrical Engineers has recently set its hand is that of improving the status of the colliery electrician. The Association gave important evidence before the Royal Commission, and is now organizing oral examinations for all electricians in order to test their competency and their knowledge of the General Regulations as to the installation and use of electricity.

Proposals have also been put forward to grant facilities for electricians to spend a part of their practical training at manufacturers' works. In exchange it is hoped that collieries will grant facilities enabling manufacturers to send their junior designers for service underground, so that they may learn to appreciate fully the conditions under which the apparatus has to work.

As was stressed many times before the Royal Commission, a large number of accidents are due to the personal factor, and the only hope of minimizing these is close co-operation in safety-first work between owners, officials, and workmen; and co-operation between the manufacturer and the user.

I think the author will agree that the functions and duties of the electrical inspector have changed very much since the early days. The electrical inspector nowadays is looked upon as a consultant by manufacturers as well as colliery engineers. His advice is of very great value, and prevents many an unsuitable design from seeing the light of day. Progressive colliery electrical engineers also look to the junior inspectors for guidance before carrying out any new installation underground. In view of these wider functions of the inspectorate and the enormous increase in the use of electricity in mines, it is surprising that there is the same number of junior inspectors to-day as there was in 1930, when the first three were appointed.

It is frequently said that the inspector's duties do not extend beyond those of policemen, but by training policemen to appeal to the motorist's common sense remarkable results in the reduction of accident rates have been achieved in Lancashire.

[The author's reply to this discussion will be found on page 636.]

NORTH-EASTERN CENTRE, AT NEWCASTLE, 12TH DECEMBER, 1938

Captain S. Walton-Brown: It is my good fortune to be in charge of totally electrified collieries, a position of affairs I have not yet had cause to regret, but I must confess to a certain degree of anxiety when reading of " black outs " and overloads on the grid system. I think, however, that the North-Eastern Electric Supply Co. will have made more adequate provision than apparently has been made elsewhere, and I have no doubt they are giving, at the present time, further consideration to continuity of supply under all circumstances.

The author is rather severe in his strictures on the mining electrical equipment of 30 years ago. I commenced with Hopkinson chain coalcutters, Blackett conveyors, D.W.A. bitumen cables, and metal-clad switchgear, in 1910. Despite more modern equipment we have not been able to improve on the filling and cutting results then obtained. The only fault of the metal-clad gear was that there was not enough metal. It is interesting to note that it was in 1852 that the first coalcutter and steel props were introduced at Seghill. It appears to me that most of the improvements in electrical equipment since 1910 have been of a metallurgical or mechanical rather than of an electrical nature. Better material has enabled motor shafts to be lengthened and the general motor dimensions made more convenient, and lightening of weights has been effected throughout. Bearings have also been mechanically improved. Even the screening of cables and more effective flame-proofing are largely mechanical changes. Buxton certificates are a step in the right direction, provided that they are not permitted to stultify the efforts of progressive manufacturers.

I have read the author's comments on mains lighting, but like many other mining engineers I am very apprehensive of using such a lighting system on modern machine mining faces. In addition, it is almost impossible to get the light from a system of mains lighting into the places where it is required, and the standard declines very rapidly as one moves away from the lighting points. I am an advocate of the cap lamp, which gives a good light where it is required, and I am astonished that no mention of this—the best form of mine lighting—is made in the paper.

While there are critics of the accidents due to elec-

Table A

SUMMARY OF ACCIDENTS DUE TO THE USE OF ELECTRICITY

Period	Fatal accidents			Accidents causing serious personal injury			Non-fatal accidents			Total accidents		
	No.	Per million tons	Percentage relative to 1931–1935 = 100	No.	Per million tons	Percentage relative to 1931–1935 = 100	No.	Per million tons	Percentage relative to 1931–1935 = 100	No.	Per million tons	Percentage relative to 1931–1935 = 100
1919–1924 (excl. 1921)	53	0·043	119	256	0·205	80	194	0·155	82	503	0·403	84
1925–1930 (excl. 1926)	49	0·040	111	267	0·216	84	220	0·178	94	536	0·434	90
1931–1935	39	0·036	100	276	0·256	100	205	0·190	100	520	0·482	100

Table B

PERCENTAGE PROGRESS OF THE INSTALLATION OF ELECTRICITY AT MINES UNDER THE COAL MINES ACT, 1911 (BASED ON THE HORSE-POWER OF THE ELECTRIC MOTORS IN USE), FOR THE YEARS 1912, 1919, 1927, AND 1935

Year	1912	1919	1927	1935
Underground:—				
Haulage	54	100	152	179
Pumping	53	100	138	150
Coal-cutting (and other portable machines in 1912 and 1919)	55	100	176	248
Conveyors and loaders	—	—	100	329
Miscellaneous	57	100	143	179
Total underground	54	100	149	180
Surface:—				
Winding	46	100	285	306
Ventilation	40	100	146	165
Haulage	53	100	164	184
Coal-cleaning or screening	57	100	186	269
Miscellaneous	38	100	172	198
Total surface	44	100	182	216
Grand total	50	100	164	195
Percentage of mines at work using electricity	44	53	53	64
Percentage increase of horse-power of motors per mine using electricity:—				
(1) Underground	56	100	146	203
(2) Surface	46	100	178	243
(3) Total	52	100	160	220
Tons of output per horse-power (electric):—				
(1) Underground	822	391	286	210
(2) Surface	1 342	520	312	233
(3) Total	510	223	149	111
Percentage increase of horse-power (electric) installed per person employed:—				
(1) Underground	58	100	171	281
(2) Surface	51	100	211	310
(3) Total	55	100	188	300

tricity in mines, I am always surprised that the results are so good. Maintenance problems and the incidence of the human element are constant sources of trouble. I am very interested in accident statistics, and Tables A and B, giving the incidence of electrical accidents and the growth of the electrical equipment in and about coal mines, are instructive.

The author has drawn attention to the fact that one of the great drawbacks of electricity underground is that it provides one more method by which an explosion of coal dust may be initiated. Experiments have shown that this can take place even without the presence of firedamp. The inflammabilities of coal dusts have been found to correspond to the reactivity of their ulmins, and the volatile matter contents can be accepted as being practically in line therewith. This principle is now being adopted as a basis for the regulation of the amount of combustible matter permitted to be present underground in mine dusts. Some diluent dusts used are a great deal more efficacious than others and also maintain their dispersibility better. Dispersibility is an important matter as it is necessary at all times that the mine dust shall rise as a body and not permit the coal dust to separate out. The sizes of the particles of coal dust and of diluent dust are also important factors in the way of respectively causing or preventing inflammability. If the electrical industry could give the mining industry a reliable apparatus by which the degree of inflammability of mine dusts could be accurately and directly tested I can promise a ready market. The same comment would apply to a reliable automatic firedamp detector, of which a large quantity will be required on or before the 1st January, 1940.

I have read the summary of the forecast with interest. Some of the items I have already referred to. I can agree that there is still a considerable amount of machinery in or about mines which as yet is not electrified, but it may be that some of this is in positions not suitable for electrification. I mention this because I prophesy that, if the Report of the Royal Commission on Safety and Health in Coal Mines is acted upon legislatively, there may be even a certain amount of electrified plant now installed which may have to be removed.

Mr. A. B. MacLean: The author mentions that there remains more than 1 million horse-power of driven machinery still to be electrified. The bulk of this plant probably consists of winding engines, large air compressors, and ventilating fans. The question of winder electrification is to some extent tied up with the source of supply of electrical energy, as the problem of dealing with the peculiar load of a winding engine is very much simplified where a large-capacity high-voltage distribution system is available. The author mentions the influence of the grid transmission system in this connection, but generally speaking it is the function of the power companies or other similar authorities to distribute electricity, and where there is a supply authority in existence with a large 20- or 30-kV distribution system there is a bigger opportunity for effecting complete electrification of colliery plant.

One of the difficulties about winder electrification is that while the colliery winder, comparatively speaking, is not a very heavy power consumer the capital cost of a new winder installation is comparatively high. Thus a reduction of 50 % in running costs may not bring in a sufficient return on the capital involved. That is perhaps why electric winding does not develop as quickly as one would wish it to do.

The conversion to electrical operation of a winding equipment should be carefully considered from every point of view. It may be necessary to alter the normal speed of winding, or the net load raised, or other factors, so as to obtain the most economic plant. Thus by a complete re-design of the whole equipment it may be possible to raise an overall efficiency of 30 per cent to something like 45 per cent.

As regards the use of compressed air generally, the following figures might be of interest. In a colliery which is all electrified and has a central compressed-air plant on the surface electrically driven, the total consumption of electricity per ton of coal is likely to be of the order of 20–25 units; for another colliery without compressed air the consumption will be of the order of 8–15 units per ton. There is obviously room here for economy, and while it is appreciated that there are certain parts of a colliery plant which may definitely require to be operated by compressed air, its indiscriminate use is to be deprecated. In many cases where there is at a colliery a central compressed-air installation it is used for supplying main and auxiliary haulages, auxiliary fans, and pumps, as well as coal-face machinery. Considerable economies would be introduced by the electrification of such haulages, fans, and pumps, and by the installation of small inbye compressors where these are required for the operation of coal-face machinery.

Mr. H. E. B. Daniell: Capt. Walton-Brown has said nearly everything that has to be said from the colliery manager's point of view, but I should like to refer to the serious state of affairs which would arise in the case of a total interruption of supply. In the case of totally electrified collieries, during the period of interruption it is impossible to get men up and down the shaft, ponies cannot be fed, and the ventilating fans cannot be run. Should the interruption last longer than a few hours, in some cases the colliery would be drowned out owing to the pumps stopping and it would be totally lost.

In regard to the subject of inbye air-compressors, I think I am right in saying that these have not been employed in collieries on a large scale unless there is a good natural supply of cooling water. Air-cooled compressors are not satisfactory in very large units. I understand that the invention of rotary compressors has gone a long way towards meeting the losses which are incurred in old-fashioned compressors of the reciprocal type.

Mr. E. L. Lamb: From the economic point of view there is no question of the very large scope for extending the use of electricity in mining work—even in those cases where mechanization has already been carried out with other media. The replacement of compressed air by electrical machinery alone should keep us busy for some time to come, for the inefficiency of compressed air is notorious. I have in mind a recent case where the saving in running cost has amounted in less than 2 years to the total initial cost of the electrical plant.

There is, however, another aspect that is not so encouraging. The author has hinted at the opposition from certain quarters to the use of electricity underground. He has also hinted rather more strongly at the steps we must take to overcome this opposition. It appears to me, however, that the crux of the matter is in a phrase that caught my attention in the earlier part of the paper. The author remarks that "The colliery electrician, often in those early days earning a niggardly wage, was frequently left without adequate supervision." I suggest that the phrase ". . . in those early days" might well be deleted.

The increase in electrical plant installed as outlined in the paper is a measure of the additional load thrown on the electrical staff, but the appreciation of the value of the plant has not been extended to the men who have to maintain it. There is, I am afraid, still a feeling amongst colliery owners that the electrician is a necessary evil. I do not raise this point merely out of consideration for the electrician. As the author says, "Maintenance, properly applied, is the best means of avoiding accidents," and if we are to overcome this opposition we must reduce accidents to a still lower level. The best means of securing proper maintenance is to raise the status of the colliery electrician, and this can only be done by making the conditions of employment such as to attract a good class of man and encourage him to improve his knowledge of electrical plant.

Mr. N. S. Walker: There is no doubt that the machine mining methods which have been made possible by the use of electrical energy have substantially increased the safety of mining operations. They have resulted in the colliery output being obtained from a much shorter length of coal face than heretofore, resulting in a marked reduction in the length of roadways to be maintained. It is not difficult to appreciate that this in turn has led not only to improved ventilating conditions, but also to increased safety of the mine generally, if for no other reason than that closer attention can be given to the condition of the roof and sides of the shorter length of roadways. Again, adequate lighting of important haulage junctions has resulted in the more expeditious and safer handling of the traffic at these points.

There is no doubt that, as the author says, in the near future more attention will be given to the complete electrification of collieries, and in this connection it may be said that in many instances where only the winding engines remain on steam the cost of operating those winders electrically would be less than the colliery boiler-house labour and maintenance costs.

In Northumberland and Durham there are connected to the North-Eastern Electric Supply Co.'s system 153 electric winding engines—that is rather more than half the total number of winders in the two counties—13 of which have been installed this year. In the near future 8 more will be added, including two each of 2 500 h.p. (r.m.s. rating).

The author has mentioned the question of low-grade fuel, but experience tends to show that the total tonnage is not of a high order and that in very many instances it can be up-graded to a saleable product in modern coal-cleaning plants. One of the difficulties of course with many of the older types of cleaning plants is the production of appreciable quantities of slurry, but by the use of froth flotation methods the coal constituents of these slurries can be recovered in a form which admits of their being readily added to the washed small coal without increase of the ash content of the mixture. In the South Wales area approximately 1 million tons of fine coal are recovered annually by flotation methods.

With reference to the author's comments on the distribution of compressed air underground, experience tends to show that even where air is compressed by mixed-pressure turbines taking exhaust steam from winding engines, the electrification of the winder, together with the installation of inbye compressors, would be a more economical arrangement. In this area over the last 2 years there has been a marked increase in the number of inbye compressors installed.

With regard to the future, I am inclined to think that one way of overcoming any remaining distrust of electricity in mines will be to provide systematic training for the personnel called upon to operate electrical equipment underground.

Mr. R. W. Mann: The progress of the manufacturing side of the mining industry has shown a lack of co-operation between the manufacturer of the mechanical portion and the technical engineering side of the electrical industry. It is right and proper that this lack of co-operation should be made good through the offices of The Institution.

There are three salient points in the paper upon which I should like to comment. It is certain that the discussions which arise out of the use of electricity in mines are out of all proportion to the hazards involved, and there is present the danger that not only do such discussions formulate suspicion in the minds of the miner and the general public, but they will ultimately serve to convince the electrical industry itself that the use of electricity adds materially to the mining hazard. The only way to make a mine completely free of hazard would be to close it, and having in mind the very small percentage of accidents due to the use of electricity it is reasonable that the attention of the industry should be directed to those causes which are responsible for the major loss of life.

It is not in any way intended to suggest that the electrical industry should not continue to give its serious consideration to the improvement of its mining products; in this connection, however, the Mines Department, which not only lays down the conditions under which a piece of apparatus shall be flame-proof, but also indicates to the manufacturer the lines on which the design should be based, may ultimately tend to remove from the electrical industry the initiative of development of new and improved designs.

By far the greater portion of such accidents as may be attributable to electricity result from lack of maintenance or carelessness on the part of the user. Maintenance of electrical plant in collieries leaves much to be desired; this is no reflection on the existing staff but rather on the inadequacy of such staff and the lack of standing which the colliery electrician has in the industry. Accidents due to the carelessness of the user must be met in some measure by the education of the user himself, and herein possibly lies a further field for co-operation between the mining industry and the electrical industry.

[The author's reply to this discussion will be found on page 636.]

EAST MIDLAND SUB-CENTRE, AT NOTTINGHAM, 6TH DECEMBER, 1938*

Prof. H. Cotton: The last few years have seen a series of terrible disasters in collieries, each of which has been associated with some type of mechanization, and I think the time has come when the whole problem of the utilization of power in mines should be reviewed very exhaustively. If this is not done, further disasters are practically inevitable. The work should be carried out by a committee of experts, chosen for their knowledge of the power problem in mines and their freedom from political or financial bias.

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* Joint meeting with the Association of Mining Electrical Engineers, the Institute of Fuel, and the Nottingham Society of Engineers.

I disagree with the author's statement that electricity must bear its due share of responsibility for the Markham Colliery disaster. My reason for this point of view is that every known phenomenon is the final result of a concatenation of successive cause and effect. The last effect becomes in its turn the next cause, and so the sequence of cause and effect continues, perhaps for ever. Consequently it is not logical to try to apportion the blame between one or two causes whose only relation is that they are neighbours in a chain of events. The cause which is the first in the series to result in a departure from the normal course of events must therefore bear all the blame, and from this point of view the whole of the blame for the Markham disaster rests with the cause (unfortunately unknown) of the runaway.

Most accidents in mines, particularly fatal accidents, are due to falls of roof, and with this in mind it is interesting to consider the relative merits of electricity and its chief competitor, compressed air, for driving mining machinery. Compressed-air machinery is much more noisy than electrical machinery, and the clatter which it makes will in all probability prevent the men from hearing the warning noises which often precede a fall of roof, while with the quieter electrical machinery there is a good chance that the warning will be heard and acted upon.

Many haulage accidents are associated with rope breakage. One great advantage of electric drive for a haulage engine is the very uniform torque of the electric motor at all speeds; in fact, it is possible to design a motor which will not produce any snatching, even at crawling speeds. This means that, given proper handling, there should be few rope breakages with electric haulage. It is true that in the event of an obstruction an electric motor will try to drag the tubs clear, while a compressed-air engine will more easily stall, and I believe that some rope breakages with electric haulage have been due to this. But the remedy here is surely the correct setting of the overload releases.

Now consider the supply of electricity to the underground workings; this is given, of course, by insulated cable. The voltage may be anything from 500 to 6 600 volts, the insulation may be vulcanized bitumen, impregnated paper, or vulcanized rubber; in fact, the cable will not differ in any major degree from a cable used for a surface installation, except that the armouring will be a double layer of steel wires. The protection of the cable from mechanical damage has exercised the minds of mining engineers from time to time, the difficulty of the problem being the instability of the floor or the sides of the roadway. Because of this instability, burial of the cable under the roadway, or its protection by means of steel troughing rigidly fixed to the roof supports, are not practicable. It is for this reason that cables have to be suspended, either at one side or near the roof, and in spite of obvious disadvantages it appears that the system will survive. Actually, the danger is not so serious as appears at first sight, the reason being the great mechanical strength of the double wire armouring.

One possibility which has to be considered is that a cable might be drawn out of a cable box by some such accident as a runaway of tubs. In such a case there would be arcing if the cable was supplying a load, while there would be a great possibility of arcing due to short-circuit or earth connection as long as the cable was alive. A solution to this problem is the incorporation of some automatic protective device such as the Williams–Rowley system, embodying an additional core which could be arranged so as to break first and, immediately on breaking, to open the switch controlling the cable.

Probably the greatest difficulty associated with mining cables is the design and disposition of the cable boxes. It is common practice to use cast-iron boxes, which, although very much stronger than those used for surface installations, are nevertheless of the same type. Since these boxes may be subjected to mechanical blows it is clear that cast iron is not a suitable material for their construction. Cylindrical steel boxes would be preferable, and there is on the market at the present time a gun-metal box of very advanced design. The removal of the danger of mechanical damage to the cable box would be met almost completely by the placing of all boxes in insets.

With regard to lighting in mines, in many mines the management are responsible for the provision of inadequate lighting, even in those localities where the lighting is fixed and where, in consequence, there are no difficulties from the point of view of installation or of the Mines Department regulations. The first essential to safety is good lighting, and it would be interesting to know how many accidents are due to inadequate lighting. The Secretary for Mines cannot do more than *ask* the owners and managers to put in a few more lights. It is quite clear that the time has come when some body should be given power to insist that adequate lighting is provided.

I will conclude with some remarks about the human factor, as this is relevant to a great many of the accidents in mines. It is now possible to design electrical machinery and plant for use in mines which when new is perfectly safe and will pass the Buxton test with ease; the question whether it will still be safe after years of service, and possibly after repairs or a series of adjustments, is a matter not so much of design as of maintenance and correct operation. With conditions as they are in a modern pit the men who shoulder the greatest responsibility are the colliery electricians, and therefore it is important that they should be the best human material obtainable. The very best men must be attracted to the industry, and the good men at present in it who are now sacrificing their talents for a very inadequate salary should be tempted to stay. The solution is twofold: firstly, the recognition of their status and responsibility; secondly, the granting of a salary comparable with their responsibility.

Mr. Richard Walker: Leakage protection surely must be one of the most important developments of mining electrical equipment, and I feel that coal mining could not have reached its present high standard without it.

The earliest trailing cables were sheathed with leather, which was sewn over the cores. The trailing cable of to-day is something quite different; one would not be afraid to crawl over such a cable even when it was being used in a wet coal-face.

On page 609 the author suggests that the work of the colliery electrical engineer " is not to be ambled through in the easiest and most convenient way. . . ." I should like to point out, however, that the electrical engineer of a colliery has never been permitted to amble through in the easiest and most convenient manner. The very nature of his work, the extremely adverse conditions with which he is continually faced, have compelled him to attain and maintain a high standard of safety and efficiency. At the same time he has hoped that the importance of his work might be fully recognized, with a higher degree of status. Prof. Cotton has pointed out that it is necessary for those in authority to appreciate the efforts he is making.

In 1931 a committee which had been appointed to consider this matter reported that the time had not arrived when compulsory certification was necessary. I then felt that it was a mistake to adopt such an attitude, and I cannot understand why compulsory certification has been objected to.

Regarding the question of joint boxes; these should be placed in recesses or be protected by very stout barriers. Those who work at collieries and are concerned with the installing of joint boxes know that this is likely to be one of the most difficult problems that the electrician has to face.

Mr. R. C. Woods: Referring to the author's remarks on the growth in the use of electricity in mines and the increase of electrical accidents in comparison with accidents resulting from other causes, is it not true to say that through the increased use of electricity some of the other causes of accidents are being eliminated? If so, once a certain point has been passed, are not the majority of accidents bound to be electrical, owing to the numerical preponderance of electrical devices, even though the use of electricity reduces the total number of accidents?

Where bare-wire signalling is employed it is necessary to make use of the intrinsic safety system, the essential of which is that the energy stored in the inductance is so limited that the break-flash is not hot enough to cause ignition. In magneto systems under service conditions the maximum amount of energy is somewhere in the region of 2 watts, with 2·5 watts as an outside figure. For battery bell systems the service maximum is of the order of 12 watts, and the inductance is controlled by spark-absorbing devices.

As regards flame-proof apparatus, one of the great difficulties, even with signalling apparatus which is fairly small, is the question of maintenance. Very great care has to be taken in producing reliable signalling apparatus, and a little difficulty with maintenance may easily cause the flame-proofing to be defective. Considering the adverse conditions under which maintenance work often has to be done, it seems to me that the heavy equipment would present even greater difficulties.

As the intrinsic safety system can provide complete communication service, the Mines Department have made new regulations, to become effective on the 1st March, 1939, requiring all telephones and signals to be of this type. I think this is a good step.

Mr. B. Nuttall (*communicated*): From a study of page 607 and the remarks of previous speakers it appears to me that closer co-operation of the local supply authority with the colliery company is required, so that the former can supplement the colliery company's own generating plant with a view to supplanting it when the private plant becomes obsolescent.

Within a 6-mile radius of Nottingham, i.e. within the electrical boundary of supply, close co-operation exists between the Corporation Electricity Department and the colliery companies, and this has been particularly the case since several of the latter have been amalgamated. The Electricity Department have been able to negotiate successfully a flat-rate tariff which has resulted in an increase of 4 500 kW of transformer capacity at the various pit-heads. As a result, Point (3) in the Summary of Forecast, page 608, has been anticipated.

Closer co-operation between the Central Electricity Board, the colliery company, and the local authority, is essential, and it is suggested that the practice of employing a secondary transmission system of 33 000 volts, which is rapidly developing in many towns having a population of 250 000 or over, should be extended; particularly so where the potential colliery load is several miles from the supply authority's station and would result in poor regulation at the generated voltage of 6 600 or 11 000 volts.

The author stresses the low percentage of fatal accidents directly traceable to the use of electricity. To my mind a fatality due to this cause is very largely fortuitous, and the paper would be much more instructive if the analysis were extended to cover all reportable accidents and dangerous occurrences *below ground.*

The discussion has revealed the fact that the status and authority of the chief electrician or electrical engineer in a coal mine is in many cases far below that necessary to ensure the continued safe use of electricity in mines. Until this position is remedied the risk of dangerous occurrences will be ever-present.

I forecast that a Central Mining Board will be set up, similar to the Central Electricity Board, to have direct and absolute control of the use of electricity in mines, and that the chief electrical engineer of the colliery will be directly responsible to this Board and not to the colliery management.

[The author's reply to this discussion will be found on page 636.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 13TH DECEMBER, 1938

Mr. D. B. Hoseason: The predominating factor governing the application of electricity in mines is undoubtedly safety. In the last 5 years there has been an increase of some 300 000 h.p. of motors in mines, and consequently many more men have been working in the vicinity of electrical equipment. On page 605 it is stated that there has been an increase in the accident rate from electrical causes during the past 10 years. It would be interesting, however, to have a rough indication of the percentage increase in the number of men subject to the risk of electrical accident.

It is clear that the most dangerous part of a mine is the actual working face, where a great deal of the hand labour which is at present being employed in the mine is located. Table C shows the horse-power installed for face conveying per 1 000 tons of coal raised, in each of the areas given in the 1937 report of the Secretary for Mines, together with the output per man shift in these areas and the cost of production. The striking feature revealed in this Table is that coal in Lancashire and Cheshire and in South Wales costs something like 25 % more per ton to produce, and the output per man shift is about 12½ % less, than in the case of areas more highly mechanized at the face. There are, of course, other factors affecting the position. For example, the South Wales and Lancashire coal-fields are extremely gassy, whilst on the other hand the pits in Scotland have very narrow seams. Nevertheless, if a serious attempt to weigh all the factors is made, there is a reasonable balance, and the figures are probably what one would expect from the degree of mechanization prevailing.

Table C

District	Aggregate h.p. of motors installed for face conveying, per 1 000 tons of coal raised	Costs of production/ton (annual average)	Output of saleable coal per man shift
			cwt.
Northumberland	0·55	13s. 2¾d.	23·28
Scotland ..	0·53	13s. 10d.	23·96
Durham.. ..	0·18	13s. 11¾d.	21·75
South Wales ..	0·024	16s. 6¾d.	20·59
Lancashire and Cheshire ..	0·11	16s. 9¼d.	20·77 (includes N. Staffs)

Returning to the question of safety, a statement occurs on page 605 that electricity has been responsible, over a period of 10 years, for about 2½ % of the fatalities. If mechanization enables us to obtain 12½ % more output per man shift, and if electricity enables us to effect mechanization to an extensive degree, then, even if we have the 2½ % of fatalities, in reality we are reducing the total number of fatalities, because we only consume a certain amount of coal and with the 12½ % more coal obtained by mechanization we proportionately reduce the number of miners necessary to obtain it. Therefore, we are subjecting about 11% fewer miners to all risks. However much mechanized mining may be criticized, and however much electricity may be criticized for the 2½% of total fatalities it produces, on balance there is a very substantial reduction in the number of men subject to risk from all types of accident.

Mr. George Barnard (Sale): I think the time has arrived when the colliery manager can no longer be expected to be a fully qualified electrical engineer, and I earnestly recommend that the status of the colliery electrician in charge be raised by official certification. On page 602 it is stated that the colliery electrical engineer is no longer the Cinderella among mining officials. Unfortunately, I know quite a number of collieries where the position of the electrician in charge is as bad as ever it was.

When I started work in the Durham coal-field we had a supply of 500 volts (d.c.), and even then we had coal-cutters and conveyors. The coal-cutters shown on the author's slides were of two types—the bar type and the chain type. During the period I am speaking of there were also a considerable number of disc-type machines, in which the revolving discs had picks fitted in the periphery. The results were reasonably good, but by no stretch of imagination could the apparatus be described as flame-proof. I went to another colliery where the supply voltage was again 500 volts, but alternating current, 40 cycles per sec. In this colliery there were coal-cutters and tough-rubber-sheathed trailing cables, but the appliances, particularly the plugs, were of poor design and construction (Fig. A). When the cutter-man wanted to reverse, he shouted to his mate at the other end of the machine and out came the flat-shaped plug, which was then turned round and pushed into the loose socket again without even bringing the starting switch to the " off " position. The coal-face was a gassy one! The bolt A was known as the " earthing-bolt "; its real function of course was to prevent the plug from being pulled out of the machine. If the bolt were missing a long nail would always do. Some of the apparatus, particularly switchgear, was doomed to failure from the start, owing to the impracticability of servicing it on site through the designer's lack of knowledge of the conditions underground.

The British Standard plug and socket is now used throughout the coal-fields and is a splendid contrivance; this, with the Williams–Rowley circuit and the modern remote-controlled contactor gate-end box, has revolutionized machine mining.

The weakest link in the chain of underground electrification is the trailing cable. Conditions underground at the face, and the treatment meted out to the trailing cables, are exceedingly severe. Some years ago a committee was formed to investigate the trailing-cable problem, and after 3–4 years' hard work it produced B.S. No. 708—1936. To my surprise, however, this " standardized " no fewer than eight types, and thus defeated its own object. I consider that the best cable in B.S. No. 708 is No. 4 (Fig. B). It will be seen from Fig. B that all the cores are the same size and are in the same pitch, which makes a very sound construction and one which withstands rough usage. As emphasized by the Mines Department in their annual reports, the provision of an earthed screen surrounding the live cores is very desirable for safety. The illustration shows this copper screen. Strangely enough, not all the trailers given in B.S. No. 708 possess an earthed sheath.

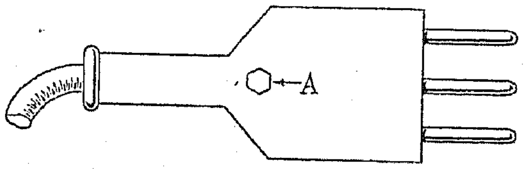

Fig. A.—Early type of 3-phase coal-cutter plug.

I agree with the statement on page 602 that all the circuits in a modern colliery should be protected by a quick-acting safety device. But what do we find is the position? In 1934 the regulations were amended so far as the lighting equipment was concerned; where the lighting apparatus was supplied from a 3-phase system the voltage was limited to 125 volts, and the neutral had to be earthed. There are, however, collieries where the neutral point of the main system is insulated, and that is allowed under the regulations. In those collieries portable power equipment operating at 650 volts is used. I should like to see the regulations amended, and if it is necessary to amend the regulations for lighting, surely it is essential for power. Instantaneous core-balance leakage protection should be fitted at every 3-phase gate-end box, and some form of protection, graded perhaps, should be incorporated in the feeder switches back to the shaft.

A few months ago it was urged by a firm of manufacturers that colliery electrical apprentices should spend a period of their training in an approved manufacturer's works. I heartily agreed, but at the same time pointed out that if that was considered advisable it was equally desirable for the key men (e.g. designers) in manufacturer's works to spend an adequate period on maintenance of the gear underground. I suggested that a committee be formed forthwith of colliery owners and representatives of manufacturing concerns to draw up a regular routine scheme, whereby there would be an exchange of trainees.

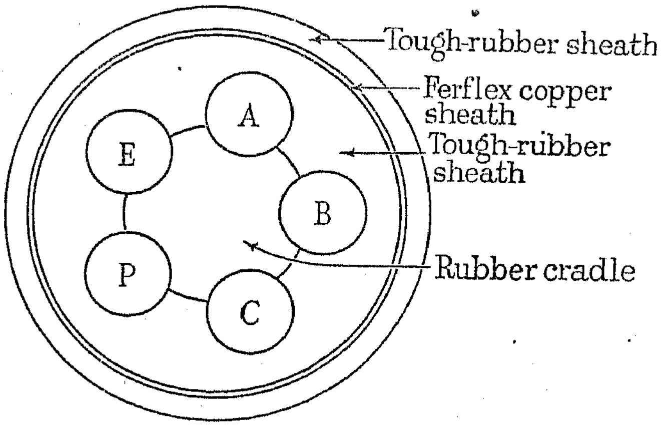

Fig. B
A, B, and C: Power cores.
E: Earth core.
P: Pilot core.

As to the Utopian idea of complete electrification of pits, I do not think this will materialize. In a pit where, at the coal-face, the proportion of methane in the atmosphere may exceed $1\frac{1}{4}$ %, the electricity must be cut off forthwith. I know of mines in Durham and other counties where the managers will not install electrical coal-cutters for that very reason. They use compressed-air machines at the face because with them it is permissible to work in a pit containing up to $2\frac{1}{2}$ % of methane. Above that value all men must be withdrawn.

With regard to hydraulic bursting of the coal wall, I think that if we can popularize this it will be all to the good, and safer than permitted explosives. Has the method met with any measure of success?

(*Communicated*): Since I made the foregoing remarks, the Report of the Royal Commission on Safety in Mines has been published. It is satisfying to note that several of my recommendations are also included in the Report.

Mr. F. C. Anderson: The author hardly does justice to the engineers who were living and active some 30 years ago when he remarks that the normal colliery plant of 1908 had a d.c. generator. In 1908 I was engaged in installing a mining electrical plant in which the current was generated at 2 200 volts, 3-phase. Such a system was necessary in that particular case because the shaft was about 600 yards deep and the current had to be taken along a tunnel 1 400 yards long. After the contract had been placed the scheme was submitted to the local Inspector of Mines, who promptly turned it down, and suggested the use of 500 volts. We tried to show him that this was impracticable, on account of the cost and the loss in transmission. He still maintained his objection, however, and the matter was referred to London. Mr. Redmayne (later Sir Richard) investigated the whole scheme and finally passed it as being sound and in accord with the regulations that obtained at that time. It embodied an earthed neutral, and many machined flanged joints which were alleged to be flame-proof.

Mr. W. Stewart: On page 597 the author states that the first electrically-driven pump was commissioned in the Forest of Dean coal-field in 1883; and from the 1937 returns of the Electrical Inspector of Mines we find that only 12·5 % of the coal won in that area was got by coal-cutters, while out of 1 052 conveyors only 47 were electrically driven. I therefore think it will be more than the author's expected period of 10 years before we get complete electrification in that particular area.

On page 601 mention is made of flame-proof enclosures; I should have liked the author to stress the point that there is a British Standard (No. 229—1929) dealing with such enclosures, and also that Test Memorandum No. 4, issued by the Mines Department, gives a considerable amount of useful information on the subject.

On page 602 the author states that alternating current is taken into the mine at 3 000 volts and distributed at voltages of 400 to 650 volts. He omits to mention the lighting voltage (110 volts), which is quite common.

On page 603 he states that the use of electrically-driven and compressed-air-driven coal-cutters is increasing. Official statistics show, however, that whereas the number of coal-cutters driven by electricity has increased enormously, those driven by compressed air have decreased in number.

I should like to have the author's opinion as to the extra cost entailed due to the higher rupturing capacity of the switchgear necessary if mining plant is connected to the grid.

Mr. E. D. Thomas: The author's figure of 2·5 % for the proportion of the mining fatalities which arise from the use of electricity is in reality too low. Most accidents in mines are due to falls, and it is in connection with this that miners mostly object to the use of coal-cutters and conveyors, for the noise associated with these masks the warning often to be heard from a roof before it comes down.

Also, is it not a fact that the use of electricity in mines is not favoured in France? Can the author give any figures as to the number of mining accidents and fatalities in France as compared with this country?

Mr. W. Fennell: I should like to make a few remarks on the question of supplying collieries from the public mains, dealt with on pages 606 and 607.

The general impression is that one must either have a generating plant at the pit to deal with all the pit's requirements, or have a complete mains supply. In Belgium, near Liége, there is what might be described as a reverse grid system. Instead of the supply being derived from conventional generating stations owned by the electricity supply authority, the greater part—probably about 75 %—is derived from a co-operative system. Electricity is generated at steelworks by gas from the blast furnaces, and at collieries by gas from coke ovens and by their steam plant. The supply authority own and operate peak-load stations (steam and water power). The owners are paid for kilowatts available for export at the times of maximum load of the system, and for units taken from them, at prices based upon those charged to the owners for kW and units when importing from the grid. The base load is obtained almost entirely from the gas-engine plant, since the supply of gas from blast furnaces, etc., is continuous. The other stations are shut down and started in very much the same way as the stations on the grid in this country, to secure maximum economy. There is a very highly developed communication and control system. Owners of plant are in every way encouraged by the prices to use efficient plant and to keep it in perfect order.

One of the chief advantages of such an arrangement is the use of low-grade fuel at the places where it is mined, saving the heavy handling and carriage or cleaning charges for marketing low-quality fuel. It also avoids the creation of spoil dumps. The system reduces the cost not only to the colliery but also to the steelworks and coke-oven owners, and ultimately to the public by reason of the economical use of by-product gas, usually wasted, also by the better utilization of private plant. It is a matter worth considering, because by such a system industries are helped. The production of the low-price Belgian steel which a few years ago threatened to put many British steel plants out of use might have been due in part to this co-operation between the steel plants and the electricity supply authorities.

Mr. W. E. Swale (*communicated*): I am particularly interested in the author's forecast that the trend of development is in the direction of a still greater use of public supply. During my time in North Staffordshire (1924–30) it was almost impossible to make out a case for public supply, as the collieries were well equipped with back-pressure turbines utilizing exhaust steam from winders and reciprocating compressors. In many collieries the chances for displacement of this type of plant are now probably better, owing to the appreciable drop in the cost of public supply in recent years, and particularly owing to the realization by the colliery owners that the fuel which they burn under their own boilers has a much higher market value than they would originally admit.

It is interesting to note from the report for the year 1937 of the Electrical Inspector of Mines that nearly 85 % of the total horse-power now used in collieries is represented by a.c. motors. This appears to indicate that alternating current is considered safer than direct current, particularly for coal-face machinery, and is a further argument in favour of public supply.

One of the few collieries in the Manchester area of supply offers a practical illustration of this latter point. Overtures had been made to this colliery for a good many years, but unsuccessfully, as they were operating their efficient back-pressure turbines. Fortunately for the supply authority, the colliery was generating direct current. The extension of the use of coal-face machinery has led to an agreement for public supply, however, and a 3 300-volt cable has been taken down the shaft. Such good use is already being made of the public supply, after not quite 2 years' development, that an annual load factor of well over 30 % is promised, and public supply should be very competitive compared with the cost of private generation.

Mr. B. L. Metcalf also took part in the discussion. The substance of his remarks will be found in the report of the London discussion (see page 611).

[The author's reply to this discussion will be found on page 636.]

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 2ND JANUARY, 1939

Mr. T. Simmons: One reason for retaining the steam winding engine is that when a colliery company has decided to install its own generating plant, mixed steam pressure turbines are installed and the exhaust steam from the winding engines is passed on to the turbines for the generation of electricity for operating the electrical machinery in and about the coal mine. I think the same reason applies to the ventilating fan. Another reason is that mining engineers have the idea that steam-operated winding and ventilating plant is more reliable than electrically-operated machinery.

Where the exhaust steam from the fan is not required, advantage should be taken of the synchronous motor for power-factor improvement, which is very necessary on colliery power plants.

With regard to the question of privately-owned generating plant versus public supply, for a new colliery the purchase of power from the public supply will obviously save the entire capital investment in power plant. In the event of negotiations for an outside supply being seriously considered, the following points and proposals should be carefully examined: (1) The duration of the contract. (2) The method or principle of charge proposed for the supply. (3) The amount of minimum annual payment to be guaranteed. (4) That the supply authorities can guarantee not only the initial load required, but such increased load as may probably be necessary owing to future developments. (5) Rebates possible if power-factor-improvement equipment is installed.

Referring to page 602, I should be glad if the author would state whether the Nottingham colliery, which is mentioned as having a total horse-power of 10 240, has its own generating plant; also, what is the horse-power of the electric winder?

I have heard it suggested that a voltage as high as 11 000 volts should be employed for underground power transmission. I consider this unnecessary, in view of the distance to which the power is transmitted. The usual 3 300-volt 3-phase supply is very suitable and it can, of course, be applied direct to the stator of the large-size motors.

On page 603 the author refers to the pit pony and the possibilities of its being withdrawn from the mines. The following figures may be of interest, showing the saving which resulted in a case where eleven ponies were replaced by four 5-h.p. single-drum haulage sets:—

	£	s.	d.	£	s.	d.
Horse haulage.						
Cost of keep for 11 ponies for 12 months at 9s. 0d. per week	257	12	4			
Eleven drivers at 6s. 6d. per day, taking an average of 5 days per week for 12 months	929	4	4			
Total cost per annum ..				1 186	16	8
Electric haulage.						
Capital outlay:—						
Cost of four single-drum haulages	192	0	0			
Cost of four 5-h.p. motors, switchgear, and cables ..	300	0	0			
Cost of preparing motor rooms	100	0	0			
Cost of haulage rope ..	50	0	0			
Total	642	0	0			
Less, sale of 11 ponies.. ..	110	0	0			
Capital outlay	£532	0	0			
Annual cost:—						
Interest 5 % Depreciation 10 % Maintenance 5 % } taken on £532	106	8	0			
Cost to run motors on full load for 12 months, 5 days per week, and an 8-hour shift, at 0·75d. per unit	97	0	0			
4 motor attendants at 6s. 6d. per day, and 5 hookers-on at 4s. 6d. per day	630	0	0			
Total cost per annum ..				833	8	0
Annual saving in favour of electric haulage ..				£353	8	8

I should like to have the author's opinion concerning the earthed versus the insulated neutral on 3-phase systems.

Mr. D. Kingsbury: Many pits in this district are struggling all the time against pits where the seams are thicker, the coal is possibly of better quality, the roads are shorter, and where there is less water and possibly a better roof, i.e. where it is easier to win the coal. Such pits frequently have to carry on with a bare minimum of equipment. I know of cases where unarmoured trailing cables are used because the owners claim they cannot afford to change over to anything more elaborate. In such cables there is nothing between the outer surface and the live conductors but tough rubber, and, valuable as this material is in certain circumstances, few people would claim that it is sufficient protection against coal-cutter picks, falls of roof, and other hazards peculiar to working faces in a colliery. To reduce the present death roll of 800–900 per annum some means of controlling the minimum price of coal appears to be essential, since there is no doubt that if more money were available a much better job could be made of most colliery electrical installations.

Practically the only form of protection against faults below-ground in a colliery is what is known as core balance or earth-leakage protection, which is inherently non-discriminative; and since grading with time-lags is emphatically not to be recommended in colliery practice, shutdowns are more frequent than they might otherwise be. This in turn means that apparatus intended to provide safety receives less sympathetic treatment than it might do; in fact it is true to say that, if there is any possible way of preventing a breaker from operating, the coal miner will find and adopt that way as a matter of course. If more satisfactory forms of protection were available this attitude would probably disappear more quickly.

Within the last few months a gratifying change has come over the world in which the colliery electrician, now termed the colliery electrical engineer, lives. He is at last being recognized as an important man, and it is hoped that in the near future he will require a proper certificate before he may be appointed.

With regard to the question of public versus private supply, I cannot agree with Mr. Simmons that it is necessary that the winding engines should be driven by steam in order to provide low-pressure steam for mixed-pressure turbine sets. It would appear more logical to scrap all the steam plant. It must not be forgotten, however, that from the undertaker's point of view a colliery load can be a very difficult one to deal with. Collieries are often situated in the country, the load is cyclic and irregular, and continuity of supply is of the utmost importance. As overhead-line transmission is usually employed, it would appear that two separate line routes are essential, because a falling tree might carry away one line or two lines on the same towers.

Mr. J. A. C. King: In the event of a fall of roof an armoured cable may not be severed but may only be subject to heavy local pressure, in consequence of which the insulation may break down between the conductor and the armouring; whereas if there had been no earthed metal as close at hand as the armoured sheath the supply would probably have been maintained. In such a case it seems to me that tough-rubber cable would be an advantage. This type of cable seems to be very reliable: in fact, after a test in which a 100-ton railway engine was run over such a cable the insulation was found to be quite serviceable, and the conductor merely slightly deformed—not appreciably reduced in cross-section.

With regard to possible co-operation between supply authorities and the mines, is it not a fact that many of the mines retain their steam plants because they are a convenient means of using up fuel which would otherwise have to be dumped, being of too low a grade to sell?

Mr. T. H. Varcoe: I should like to refer to the work of W. C. Mountain and other pioneers of the use of electricity in mines. These men worked at a great disadvantage because, as is stated in the paper, until about 1908 generally direct current only was available.

Electric coal-cutters were developed in this country by designers such as F. W. Hurd, having been first introduced in American coal mining as early as about 1889. A lot of valuable experience of mining electrification was obtained in the U.S.A., where conditions were more favourable than in this country, as the mines were not so fiery and had very thick seams. American manufacturers of coal-cutting machinery afterwards tried out their ideas in British mines, with disastrous results so far as they themselves were concerned. I remember that in 1905–7 certain American manufacturers were endeavouring to secure what they could foresee was a good market here. They did not know the conditions in our mines thoroughly, however, and attempted to use American-made coal-cutters, which, apart from inferior insulation, were not fitted with enclosed gastight-type motors. They imported their own machine-men to teach the British colliers how to use the machines, as the selection of a suitable driver for a coal-cutter was a matter of great importance.

[The author's reply to this discussion will be found on page 636.]

WESTERN CENTRE, AT CARDIFF, 9TH JANUARY, 1939

Mr. S. B. Haslam: I am glad to see that at last the importance of this branch of the industry—electricity as applied to mining—has been thought worthy of a paper. The author gives the total electrical horse-power installed in mines as approaching $2\frac{1}{4}$ million, and mentions 5 500 million units as a possible annual consumption. Therefore I hope that in the near future this Institution will consider the formation of a Mining Section, and will collaborate with the Association of Mining Electrical Engineers in the examinations held by that Association, so that the holder of the latter's first-class certificate may be exempt from future examination and, with adequate experience and responsibility, be eligible for Corporate Membership of this Institution. I am confident that the benefits would be mutual.

Now a few words on the numbered paragraphs in the author's forecast (page 608).

(1) I am afraid that it will never be possible to electrify the mines completely in this district. The author has referred to the hostility of the miners, but the hostility of the inspectorate is even more evident. I do not think we can expect in our time the complete electrification of face machinery, at any rate in the gassy mines.

(2) To some extent I cannot agree. As regards the smaller pits, yes! but I do not see how any supply authority can compete with the costs of an efficient privately-owned generating station if the costs of distribution and of transformer losses is included.

(3) At the same time I agree with the author as to the opportunity for co-operation, and if some agreement can be reached whereby the collieries can take all, or even part of, their requirements from the supply authority without having to meet increased costs, it will certainly be of mutual benefit. I am not one of those who consider that the risk of a " black out " should be the limiting factor.

(4) Yes, and no! Every case will have to be examined carefully on its merits, and there will undoubtedly be found many cases where electricity can be used conveniently, safely, and economically, for instance inbye compressors as against long and wasteful pipe lines from the surface.

(5) Here I am entirely with the author. Underground lighting by electricity has made very little progress in past years and I should like to see this subject taken up and examined most thoroughly. At present, the most popular form of roadway lighting seems to be the self-contained air-driven electric lamp, and I submit that herein lies a considerable opening for research and inventive capacity.

Mr. W. Hyland: I agree that public supply as against privately-owned stations is one of many aspects when considered from the mining engineer's viewpoint and I feel, with the author, that the change-over, even if offered on an equivalent cost-of-production basis, is bound to be slow owing to the inertia of opinion on the safety point of view. Compare a coal mine with a steelworks. It is significant that even steelworks install their own emergency plant, and the coal mine would undoubtedly require such plant. The difficulty arises, however, in determining the amount of the total load that can be classified as necessary in an emergency. In a steelworks the proportion is comparatively small, but in a coal mine, when winding and ventilation come under this heading, the proportion is naturally much higher and tends to make the case for private plant somewhat better. There are other considerations, however, which bear upon the position and in which the public supply will show up favourably; for instance, obsolescence of large plants, where the capital expenditure may become considerable, in addition to the charge for interest and sinking fund, or depreciation, whichever the case may be. On this account it will be seen that the major portion of the cost of the units generated is due to capital charges and not to coal, or what one might term the cost of production.

In the discussions it has been stated that the private station can produce much more cheaply than a public supply. If capital charges are neglected and the coal used in such a station is charged at only a nominal rate one would expect the cost of the electrical energy to be cheaper on paper than any public supply tariff. It is well known that coal of an inferior quality is used in generating stations at the pit-head. This fuel is very dirty, would be prohibitively expensive to clean, and contains only 55 % saleable coal. It would obviously be unwise to suggest this quality of fuel for use by public supply undertakings. The peculiarity of the position is that the coal owners control the price of electricity through the price of fuel, and, as the author points out, there is great scope for co-operation in reciprocity of business. Statistics* show that in 1936 the number of units generated privately by the coal industry was approximately 8 % of the output of public supply undertakings.

Regarding the unreliability of public supply and the grid, it must be admitted that there have been outages, some serious, but the majority less serious. It will be agreed, however, that interconnection must give a greater safety margin as regards continuity of supply than that of isolated stations, provided that the plant dispositions are correct. At the same time, whatever the system, it is impossible to say that outages will never occur.

Mention has been made of the experiments at Buxton demonstrating the ignition of mine gases by a very small electric spark, and the apparent ineffectiveness of the large spark caused by the cutters on stone; I suggest that the explanation lies in the fact that the spark is much hotter than the friction temperature of the stone particles, whilst, in addition, an electric spark actually breaks down the atomic structure of the air.

Mr. L. Howles: With reference to the desirability of co-operation between public supply authorities and colliery owners, in South Wales practical measures of co-operation are already in hand. They cover two major fields. First, the public supply authority, when obtaining a large portion of its coal requirements, has offered a flexibility to the coal owners by permitting coal to be drawn from a number of pits as will best suit the operating programme of the collieries in question, thereby enabling the supply of fuel to the public utility to go hand in hand with the sales of other grades of fuel from the same pit. Secondly, interconnection arrangements have been made between the public supply system and the pit-head generating plants to enable the benefits of public supply to be obtained for the increasing electrical demands of the colliery without the necessity of the latter immediately scrapping valuable plant already installed. In the discussion a point has been made that the major consideration before colliery engineers is security of supply, and it has been suggested that public supply systems have been known to be unreliable. It is, of course, a fact that public supply systems are subject to occasional troubles, but the same can equally be said of private plants, and the question therefore is one of degree. With public plant, especially since the completion of the grid, the selected stations are so interconnected that even a major plant breakdown would not cause disabilities for more than, in the worst possible case, a few hours. An equivalent breakdown in private plant may well involve repair work taking weeks, and in some cases even months, to repair. During recent years many colliery owners in the South Wales area have changed over from private plant to public supply, with complete satisfaction.

The question of the relative cost of public and private supplies has also been raised as one of principle, and the view has been expressed that the necessity for transmission plant in the case of the public supply must inevitably make the supply costly as compared with pithead plant. This is not a fact, but to deal with it exhaustively would take too much time now. I would, however, refer to the diversity factor, which is one of the fundamental items permitting public supply to compare very favourably with pithead plant, especially if the service given is comparable.

Mr. F. L. Coombs: A previous speaker has asked whether the author has any evidence of signalling devices in pits having been operated by induced voltages radiated from high-voltage transmission lines above the surface, when those lines were functioning under fault conditions. In my opinion it is highly improbable that signalling devices below ground can be operated in that way, owing to their relatively small network and to their being very effectively screened by the earth between the pit bottom and the surface.

[The author's reply to this discussion will be found on page 636.]

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE, AT LIVERPOOL, 23RD JANUARY, 1939

Mr. F. B. Lawson: While stone-dusting has limited the size and effect of an explosion, unfortunately it is only a palliative and under the new regulations which are now being drafted the figure of 50 % non-combustible in the present Act is raised to 75 %. It apparently depends on the volatile matter in the coal as to what quantity of stone-dust is required to dilute the coal dust.

It is perfectly true that electricity, unless most carefully handled, is what is known as an "added danger," and the Royal Commission has recommended further restrictions, which I understand it is the Government's intention to implement by legislation. The author has, however, made his point, namely that the enormous increase of electrical power underground has had a very small effect on the number of explosions and the death rate in mines. This very desirable result has been brought about through the assistance and research of the manufacturers of switchgear and electrical plant generally, together with the work of the Safety in Mines Research Board, and the co-operation of colliery electrical engineers. If any of these three partners had been lacking in energy or ability, the increase in the use of electricity in the mines would not have been anything like so great as it has been.

Mr. O. I. Butler: Locomotive haulage is dismissed rather lightly by the author when he says that it can rarely be applied to advantage in a mine roadway not constructed for this method of haulage. Conditions are mentioned which are too severe to allow of locomotive haulage, but these same conditions are, in my opinion, liable to be too severe to allow of even rope haulage. On main roadways, in order to avoid derailment at reasonable rates of traffic, it is essential that special attention be given to the construction of the roadway. I would suggest that, as far as main roadways are concerned, conditions in many collieries are satisfactory for locomotive haulage. With regard to roadways near the coal-face, whatever the system of mining, locomotive haulage is much more mobile than rope haulage. Again, the desirable end of eliminating the pit pony would be more quickly achieved by the use of light locomotives near the coal-face.

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* H. Storey: "Non-Statutory Undertakings," *Power and Works Engineer*, 1939, vol. 34, p. 23.

I should be glad if the author could state the total number of electric locomotives at present in use in the coal mines of the British Isles.

My experience shows that colliery authorities in the British Isles have a tendency to introduce coal-cutters in the first place in order to reduce labour charges at the coal-face. This is followed by reorganization of the method of transport, which is gradually attuned so as to be capable of dealing with the increased output. This view appears to be substantiated by Fig. C, embodying statistics taken from the annual reports of the Chief Inspector of Mines. The graph tends to give the impression that the number of coal-cutters installed is reaching saturation point, but this impression is misleading, as coal-cutters had still to be introduced into over 50 % of the mines at work in 1935. I should be interested to have the author's comments on the graph, particularly with regard to the apparent saturation value of the number of installed coal-cutters.

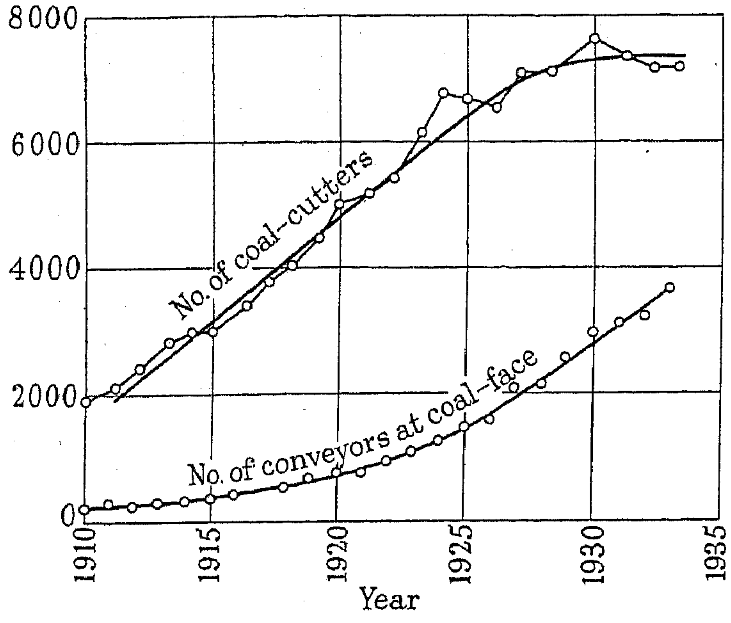

Fig. C

Mr. L. C. Grant: I am astonished that the standard of electric lighting in colliery workings is as low as the author's figures indicate. It is not at all clear to me why coal mines are in most cases very badly illuminated. Prof. Thornton has produced two methods of electric lighting for pits, which seem to be as safe as one could possibly wish. One of these is his low-voltage high-frequency system, which operates at about 300 cycles per sec. and produces an arc of non-calorific characteristics. There is commercial apparatus available for producing the 300-cycle supply, which can be used with ordinary commercial lighting equipment. It is therefore extremely difficult to know why such a lighting system has not been used. Colliery owners must know that poor lighting means a high accident risk, and accounts for some of the miners' eye troubles.

The miner's portable lamp or Davy lamp has been greatly improved in lighting efficiency, but the light output is still very small compared with the output of an incandescent electric lamp. Prof. Thornton and other investigators have evolved commercial electrical mines lamps of reasonably high intensity which are perfectly safe in the worst mines. Not only this, but the Thornton lamp will give a visible warning of dangerous gas accumulations. I cannot understand why it has not been adopted on the scale which it appears to merit.

One other point: in the early days of electrification, colliery managers seemed to think there was no case whatever for bringing electricity into the colliery from a public supply authority. Nevertheless, the development in this direction even before the War was astonishing. I suppose one of the reasons why electricity made such inroads was because the abundance or coal at the pit-heads was in some respects the undoing of the coal-fired plants. Many of the old colliery steam plants consisted of boilers installed in the open air, frequently without lagging, with wheezing steam joints and often with bad stoking—usually hand stoking. In those days coal for power-station use was bought at about one-sixth the present price; even with present-day prices public supply competes just as efficiently with the steam plants.

Mr. B. Welbourn: The author has referred to some estimates which I made some years ago in regard to the possible consumption of electricity in the mining industry, and everything that has happened since goes to confirm that these estimates are on the way to realization. But the full realization of these estimates depends on sound engineering, both mechanical and electrical, and on getting the confidence of those who have to work in mines in this country.

The author seems to have taken it for granted that owners are anxious to electrify their collieries; but he does not give any reason why they should electrify, nor does he mention any savings that can be realized by electrification.

I feel that, in view of the increasing importance of the colliery electrical engineer, everything that can be done should be done to improve his status, and I hope that the Association of Mining Electrical Engineers will some day have its own Royal Charter.

Mr. T. Hodge: The paper revives some memories of my own regarding the introduction of electricity in coal mines.

The first is the lighting of a pit bottom in 1897, the current being direct, 110 volts, conveyed by a concentric cable 400 yards long suspended by huge wooden cleats fastened to the side of the pit shaft. Trouble arose frequently through the cores getting crushed together and causing short-circuits, due to the weight and vertical suspension.

The next is the introduction of electric power—3-phase, 40 cycles per sec., 500 volts—in what was, I believe, the first 3-phase plant ever put down in England for colliery work. It was installed early in 1898 at Park Colliery, Garswood, Lancashire, and was used for pumping, driving a 35-h.p. motor operating an air compressor for coal-cutting, and for lighting above and below ground, the lamps being connected two in series. The cables in the pit shaft, 300 yd. deep, were rubber-covered and driven into the grooves of special wood casing fastened to the side of the pit shaft, ending in a distribution board with open-type switches and fuses in the under-manager's office. From this point three rubber cables were carried on insulators fastened to the props, and on to the pump motors 1 800 yd. away, without any means of disconnecting. The first electrical mining fatality I heard of occurred at this plant under-ground, causing the death of a young mining student who was playing a joke and got his hand across the line contacts of one of the switches.

With regard to signalling and electric sparking, I have always been sceptical as to whether this could cause such a disaster as occurred at Senghenydd Colliery; because in view of the low voltage generated by the Leclanché cell, and the great lengths of most of the lines, it was often impossible to ring the bell at all; in fact, we used to test the bare wires with the tongue to find whether any current was flowing. However, the new regulations have made signalling more efficient and safer for all concerned.

As to the future, whilst regulations and manufacturers are doing their best to make for efficiency and safety, the strenuous conditions under-ground will always necessitate care in the maintenance of electric apparatus. And, in spite of recent developments, I would ask the author whether he considers that electric power or lighting from the mains will ever be perfectly safe at the coal-face, where it is necessary to use safety lamps. Of course, if the Coal Mines Regulation Act, which states that the ventilation must always be sufficient to neutralize the gas, could in every circumstance be carried out to the letter, electricity would be the greatest boon to the miner in his hazardous task.

With regard to electric winders, in view of the depleted state of the coalfields it is doubtful whether there will be a large demand for these in this country in the future.

Mr. E. W. Ashby: It appears that the extension of the use of electricity in mines is a question of confidence and economics. So far as the collier is concerned his point of view is readily appreciated. The author refers to two severe accidents due to the presence of electricity under-ground, and so long as a supply exists there it is a potential danger. Usually some severe accident such as is caused by a roof fall or by runaway trucks results in the fracture of the mechanical protection provided for some piece of electrical equipment, and it cannot be disputed that although such an accident is not initially due to electricity the severity of the ultimate effects may be greatly aggravated by electrical fire and possible explosion.

So far as the supply industry is concerned it must be the aim to obtain the confidence of the colliery owners. Reliability is essential, and the supply to the colliery transformer must be maintained always. The price per unit must be sufficiently attractive. The figure has been mentioned of 5 lb. of coal per lb. of steam, but in an address by Mr. H. A. McGuffie* recently four instances were cited of typical colliery generating plants in which the highest cost per unit was 0·3d. and the lowest 0·265d.

The official attitude to coal-face lighting is expressed in the General Regulations under the Coal Mines Act, which states that application may be made for approval of a Special Regulation if it is desired to use electric light at the coal-face or loading gate.

Mr. E. G. Taylor: May I have the author's opinion as to the future method of machine cutting and conveying at the coal-face? Will this be operated by means of compressed air or by electricity? To my mind the future of electricity as far as under-ground working is concerned depends, to a large extent, upon this factor.

Mr. J. B. Sproston: With regard to Mr. Grant's remarks about the poor standard of lighting in coal mines, the instances he has in mind must have been chosen from the very distant past. He has no need to go out of this district to find mains lighting on main roads, and, further, in some nearby collieries the whole length of a coal-face is lit by electric power generated on site. The standard of lighting in mines is more or less governed by legislation, and mineowners can only introduce a standard of lighting which has been approved by the Mines Department. If anything is lacking it is the ability of the electrical industry to produce good lighting, or lamps which are safe to use under all conditions.

Turning now to the author's observation that 1 million horse-power remain to be electrified in mines, I should advise the industry to tread warily in trying to capture that portion, because I feel that the horse-power referred to is to be applied on the coal-face. The principle of applying electricity on the coal-face is receiving a good deal of opposition from the miners' leaders and others, and, moreover, the recommendations of the Royal Commission (just published) have made the conditions very stringent.

There are, of course, advantages to be obtained with electricity compared with compressed air. The salient feature of electrical operation is quietness, and whilst this in itself is a matter tending to greater safety it is more than counterbalanced by the dangers of handling electricity in uncertain and varying conditions—conditions which in the best of mines are not ideal. But, to strike a more optimistic note, there is great scope for the further use of electricity to within 300 yd. of the working face. Its scope can be very much extended in conjunction with inbye compressors and main haulages.

[The author's reply to this discussion will be found on page 636.]

SCOTTISH CENTRE, AT EDINBURGH, 24TH JANUARY, 1939

Mr. H. A. McGuffie: The author does not mention the use of concentric vulcanized-rubber lead-covered and wire-armoured cable. This type of cable was actually in use for power circuits before 1900. Full credit should be given to Mr. Mavor for introducing the concentric system, which was undoubtedly very safe and reliable compared with the alternatives which were available at that time. The concentric system in general proved quite satisfactory on small installations, but in my opinion it is not suitable for large installations. At that time Mr. Mavor also introduced ironclad switchgear and other fittings. I suggest that the author should consult Mr. Mavor on the history of mining electrification, as he could no doubt give some valuable information which might be added to the paper. I refer particularly to the question of when armoured cables were first used.

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* *Mining Electrical Engineer*, 1938, vol. 18, p. 421.

I agree with the author that the wages paid to colliery electricians are in many cases extremely low. This point has been raised in evidence given before a Royal Commission, whose report has lately been issued. The colliery electrician of to-day is a very different person from his counterpart of, say, 30 years ago. His electrical knowledge now has to cover a wide field. In general his status has been improved, and no doubt this has resulted and will result in his wages being increased.

I am not quite in agreement with the author's remark as to it being common to find in 1908 an installation below-ground in which no single item of plant was metalclad. In Scotland at that date extensive use was being made of the Mavor and Coulson concentric system, and it was about 1909 that metalclad gear was first being considered for systems other than the concentric. At this stage the late H. W. Clothier started his investigations which led to the adoption of sound metalclad gear.

I should like to mention that haulage underground by Diesel locomotives is now being considered by one of the Fife collieries.

Turning to the subject of "Lighting" (page 603), the design of the electric safety lamp has greatly improved in the last few years. For instance, to-day we have lamps fitted with gas-testing arrangements and shot-firing equipment (for special work). Furthermore, certain designs of these lamps (known to the collier as "a.c. lamps") are actually charged from an a.c. supply, a small rectifier and cut-out being introduced as part of the lamp. The small rectifier limits the amount of charging of the cells and also simplifies the connecting-up process. One of the troubles with electric lamps was the casual way in which they were charged; the man in the lamp room took them off charge when he "thought" they were ready. Nowadays lamps are treated in a more scientific manner, with the result that they continue to give a satisfactory light throughout the shift.

I agree with the author that there are many cases where electricity might be taken farther in-bye and air compressors installed. In Scotland there are now few compressed-air installations of any great size. Compressed air is, of course, used for driving mines and tunnels, portable air-compressors being installed for this purpose.

I come now to the subject of privately-owned generating plant versus the public supply. In the case of the smaller collieries in outlying districts, such as occur in Scotland where the life of the field may be short, careful consideration should be given to the question of obtaining electricity from an outside supply. The capital expenditure involved in laying down boilers, engines, and buildings is considerable. A large proportion of this expenditure can be avoided if a supply of electricity can be obtained at a reasonable figure which will allow of an all-electric colliery. I agree that in many of the smaller collieries saleable fuel is often made use of for generating electricity. The position, however, in connection with the larger collieries or groups of collieries, and coke ovens, etc., is entirely different. Here the generating plant is of the latest type, the boiler plant being suitable for dealing with low-grade fuels which are almost unsaleable and may be difficult to deal with from a transport point of view. The larger collieries in many cases generate very large quantities of energy and distribute this over extensive areas at voltages up to 22 kV. Their transmission schemes are up-to-date, usually of the ring type, with the result that there are very few failures of supply. In fact, I cannot accept the author's remark that an outside supply would be more reliable. These large schemes allow of quick developments taking place at the individual collieries without any serious effect on the generating capacity of the whole scheme. I am of opinion that unless the grid supply can be given in such cases at an all-round figure of, say, 0·25d. to 0·3d. per unit, there is not much chance of it being made use of in these large colliery undertakings.

In the spring of last year I obtained some reliable figures as to the generating costs of two of our largest colliery undertakings in Scotland, where large private plants are in operation, furnishing a supply over very large areas. The generating costs (delivered to the main switchboard) of the two undertakings were 0·265d. and 0·267d. per unit respectively. The quantity of energy generated by the two concerns was in the neighbourhood of 146 000 000 units per annum. Since these figures were furnished the load of the undertakings has increased considerably, with the result that in all probability a figure of 200 000 000 units per annum will be reached at an early date.

Up to the beginning of 1937 the load factor at collieries was extremely low, at the best approximately 18 % to 20 %. Owing, however, to the mining developments underground which have called for supplies of electricity on the back shift—that is, the late part of the complete shift—and the fact that the pumping load has in many cases had to be rearranged, the load factor is improving considerably. In some of the larger colliery undertakings it is now in the neighbourhood of 60 % to 65 %, taken over the colliery working period of 11 days (in Scotland we have usually, every fortnight, a Saturday off). In certain groups of collieries the electricity department have actually found it profitable to pay for underground storage or sumping arrangements for water, so that they could pump the water at the most convenient time. If the colliery owners were pressed, and were paid for it, they could in many cases make these arrangements, and this would at once improve the load factor. A colliery private generating plant can to a certain extent adjust the load factor, and in this respect has an advantage over a public supply authority.

The load at the collieries is increasing at a very rapid rate, principally for the following reasons: (*a*) The additional amount of power required on the back shift. (*b*) The increase in the size of washing and screening plants. The additional load is resulting in power being required for much longer periods per day. For instance, I have a case in mind where a few years ago the demand on the generating station was about 1 800 kW from, say, 6 a.m. until about 3 p.m.; the load then dropped to about 500 kW and remained at this figure during the back and night shift. When I visited the colliery a few weeks ago I found that the load from 6 a.m. until 5 p.m.

was approximately 2 000 kW. It then dropped to about 750 kW and remained at roughly this figure during the back and night shift. This increase in load was solely due to the washing and screening plant being run until the evening and to the additional coal-cutter load plus a pumping load which had been transferred from the day shift to the night shift.

On page 607 the author states that in 1937 some 12 million tons of coal were burned under colliery boilers for generating power. Perhaps he would be good enough to tell us from what source these figures were obtained.

I am not in agreement with item (2) of the author's "Summary of Forecast," being of the opinion that in the case of large collieries or groups of collieries the grid supply will not be considered unless it can be given at not more than 0·3d. per unit. In regard to item (5), I do not attach a great deal of importance to the lighting load, as under the best conditions this can only amount to a small proportion of the total power load.

Prof. W. H. McMillan: There is no single factor capable of contributing more to the success of a colliery undertaking than a plentiful supply of adequately distributed lighting, whether we look at the question from the standpoint of efficiency, production, or reduction of accidents. But even if we could neglect the question of safety, and even if the economic aspect could be ruled out, the problem would differ in some important respects from that which obtains in factories and workshops on the surface. There is indeed the possibility that an indiscriminate use of mains lighting might defeat its own object, owing to difficulties in connection with glare. Other factors, including the almost complete absence of reflection, the limitation of space, and obstacles to distribution and design of fittings, also affect the problem. There is ample room for the extension of mains lighting in main haulage roads, especially where the reflection ratio and therefore the background brightness can be improved by artificial means, such as whitewashing (where the roadways are not too wet) or the application of some light-coloured dust for stone-dusting purposes, to which the author refers.

There are, however, many arguments against the view sometimes expressed that if electric coal-cutters and conveyors can be used on the face, why not mains lighting. Such a view implies that safety is the only problem; but apart from safety altogether it does not appear to be appreciated that in many cases in seams of moderate thickness, and particularly in the thinner seams worked by coal-cutters and conveyors, tests have shown that much better illumination is provided by the more modern forms of portable electric lamps than by existing mains lighting systems. In fact, the mining engineer is waiting for the electrical engineer to develop with the co-operation of the illuminating engineer a system which can be successful applied under these conditions. Any such system, to be superior to modern portable lamps, would require to be much more flexible than the present system. In the development of the ideal universal system the questions of glare, background brightness, and flexibility, apart altogether from the questions of safety and economy, must receive more attention than is demanded in surface installations or even in main-road installations underground.

It is not generally appreciated that the fuel cost of a colliery is comparatively small and in many cases nil. Collieries are very often producing a fuel which they cannot get rid of, and which if they wished to sell would have to be washed, and this would probably add 1s. or more per ton to the cost. This sometimes large quantity of inferior fuel they can use themselves, and so produce electric power at a price which competes more than favourably with that offered by any central supply authority.

Mr. G. G. L. Preece: The whole problem of safety in coal mines is indissolubly linked up with the status of the colliery electrical engineer. In the early days of electricity in mines the qualified colliery electrical engineer was in the minority. He was miserably paid, he had no authority, and generally speaking he had to put up with whatever plant the management liked to give him. As a result of the efforts of the Home Office and the Association of Mining Electrical Engineers, the status of the colliery electrical engineer has been vastly improved. But there is still a good deal of room for improvement; it rests with the management of the mines, but above all with the Home Office, to see that none but qualified engineers are allowed to be responsible for the supervision of electrical plant in the mines. The Home Office has done a good deal by the Buxton tests, but quite a lot of unsatisfactory plant is still installed in collieries, largely owing to the fact that the man who buys the plant does not consult sufficiently the colliery electrical engineer. If the colliery electrical engineer were given a certificate of status, and made responsible for the apparatus, he would have to be consulted with regard to the buying of it. When we reach the stage where no electrical plant for use in a colliery is bought without the stamp of the colliery electrical engineer being placed upon it, the question of the safety of electrical plant in mines will be solved to a large extent.

Mr. D. Martin: Prof. McMillan has referred to the slow progress made in coal-face illumination. I should like to recall that Mr. R. M. Russell, of Glasgow, shortly after the War developed a system which, in collaboration with the late H. W. Clothier, was carried a stage further at considerable expense. The fittings had to be made flame-proof, and were therefore expensive. Maintenance, and the labour costs involved in moving the apparatus forward as the face advanced, also added to the expense. Many other systems have since been developed, but expense seems to be the prime cause militating against their general adoption.

In another connection the Association of Mining Electrical Engineers has, ever since it was founded 30 years ago, adopted the policy of "safety first." In discussions at meetings and by educational methods as well as by research, we have revolutionized the practice of the application of electricity to mining; so much so that the high standards aimed at have been extended to ordinary everyday industrial work. We have always found it expedient to work in collaboration with the Mines Department officials, and that we have been on the right lines is evident from the report of the Royal Commission on Safety in Mines, recently published. In it they accept the standard which we have set for the examination of competent colliery electrical engineers, 850 or more of whom in the United Kingdom now possess one or other of our certificates awarded as the result of these examinations. It is a remarkable fact that not one of these men is, or has been for any length of time, unemployed.

The Minister of Mines has indicated in the House of Commons that the Government propose to accept the recommendations of the Royal Commission. Among them is the compulsory certification of colliery electrical engineers, so that none but those qualified may be employed in the repair and maintenance of the electrical equipment. When one fully appreciates the large amount of electrical plant now installed in mines and the care involved in its design to make it safe, it is obvious the Royal Commission could not have come to any other conclusion.

Mr. G. A. McLennan: It would be interesting to know whether the output of coal per man in the mines has increased as the result of the introduction of machine mining.

Mr. McGuffie referred to the fact that the Fife Coal Co. are considering the use of Diesel locomotives; I should like to say that in the shale industry we are already using a Diesel locomotive in one of our mines, and that another one will be in use this year.

I should like to ask the author whether he has any ideas as to what the trend of progress should be in regard to underground lighting.

Referring to the author's suggestion that more use might be made of the grid supply, I have on several occasions made inquiries about changing over to a grid supply, and have generally found that the price per unit would work out at between 0·6d. and 0·7d. I think the C.E.B. should abandon the kVA charge, seeing that a colliery load is essentially one where there are considerable peaks, due to winding, pumping, and haulage. I agree with Mr. McGuffie that the grid supply must get down to a figure of at most 0·3d. per unit before it will be of any use to the colliery undertakings. Another point in connection with grid supplies is that they are subject to too many shutdowns. We have one very small supply at one of our works, and within the last few weeks, for example, it has been continually interrupted. It was as a result of these shutdowns that we were forced to put in a stand-by set.

I agree with Mr. Preece that the colliery electrician should have some say in the type of plant which he has to use in the colliery, but I would remind him that some of the recent disasters due to electricity have been caused not by defective plant but by defective maintenance. In most cases it is not so much a question of unsuitable plant as failure of the human element to install and maintain that plant in a safe manner.

Mr. George Henderson (Edinburgh): I should like to point out that there is still a great deal of difference of opinion among colliery electricians regarding the manufacture and use of mining electrical machinery, e.g. on the question of earthed versus insulated neutrals.

I do not agree with the author that colliery apparatus should be so constructed that it can be maintained underground. The colliery electrician himself will feel safer if he is permitted to bring all apparatus to the surface for maintenance purposes. Mr. McLennan has mentioned that accidents have occurred in connection with first-class apparatus owing to careless maintenance, and the fact that such accidents can occur suggests that it should be made compulsory to open up flame-proof apparatus on the surface.

The author mentions that direct current has many advantages for winding purposes, and it is therefore surprising to find that in Scotland a.c. winders are used almost exclusively. I think that d.c. winding only comes into consideration for very big installations where the peak load would be excessive.

As regards the question of power supply from a public authority, in Scotland there are many colliery companies which generate at a central point and distribute the power themselves, winding, pumping, etc., being done electrically. I have never yet met a colliery engineer who was willing to buy electrical energy from a supply undertaking unless his power plant was obsolete and had to be renewed, and the coal output of the mine was limited to, say, 10–20 years.

I should like to hear something more about why electric lighting from the mains is not used inbye.

Mr. J. Frame: Between 1910 and 1937 there was a great increase in the quantity of coal cut, but my contention is that some time before 1937 stagnation point had been reached. Even in 1937, 43 % of the total quantity of coal produced was not machine-cut; and of this quantity some 13 million tons was obtained by pneumatic pick, to which there is no electrical equivalent. Why is there no electrical equivalent to the pneumatic pick? Of the coal which is not machine-cut, not less than half could be won with a mechanical pick much more safely (owing to the decrease in the number of shots necessary) and economically than it is at present. At the moment many colliery managers have to deal with coal which is just too soft to be cut and yet too hard to be hand-won. This problem provides an opening for an electrical engineer to do something of great value to the mining industry.

Prof. F. G. Baily: Everyone who can recall the electrical equipment of collieries in the first few years of the century will agree about its imperfection. While rapid improvement was made in houses and factories under the stimulus of stricter specifications, the work underground was extremely casual, although the conditions were more severe and dangers resulted from faults. The colliery electrician had little authority and was forced to use such appliances as were supplied to him, however unsuitable they might be. It seems to have dawned very slowly in the minds of colliery owners that coal-winning is an engineering job and one carried out in peculiarly difficult conditions, demanding a highly skilled type of engineer.

In discussing the supply of electric power to the pits the author advocates a connection to the grid as the cheapest source of power. In an Address to the Engineering Section of the British Association in 1934* I took the opposite view that by using the refuse and lowest grades of coal the pits could produce power more cheaply than was possible in the present selected stations, and that they had sufficient of this cheap coal to supply a large amount of power to the grid. That many pits use an extravagant quantity of refuse coal under their boilers is largely because they have no other use for it, and this is the cheapest way of dealing with it. At one group of pits I have examined, with a load of 4 000 kW at a load factor of 70 %, the electrical energy is produced at the rate of 2·2 lb. of coal per unit, the calorific value being about 7 300 B.Th.U. per lb. as fed in, equivalent to 1·4 lb. per unit for coal of 11 500 B.Th.U. per lb. The coal was quite unsaleable, but it was allotted a value of 3s. per ton, and the total cost of generation, including wages, repairs, interest, depreciation, local rates, etc., came to $\frac{1}{6}$d. per unit. It is absurd to suggest that this colliery should take its power from the grid, and there seems no good reason why many other collieries should not do equally well. From the author's figures of units consumed at collieries, the consumption of this coal for colliery purposes would be some 5 million tons, leaving 7 million tons for power to be supplied to the grid, and this would provide nearly one-third of the total consumption of electric power in Britain, all of it being absorbed in areas within 50 miles of coal-pits. There is certainly a good case for co-operation between the electric supply authorities and the collieries, but the direction should be the reverse of that suggested in the paper. I agree that a Power Board of some kind would be required and I indicated this in my B.A. Address; but, whatever the means adopted, there is the possibility of considerable economy in cost and consumption of fuel. There is a further waste of refuse coal by the leaving of it below ground, for the good reason that it is not worth bringing up; but if it is saleable or profitably usable there will be greater care to win all the coal in the seam.

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* Report of the British Association, 1934, p. 145.

It is often urged against this idea of generating stations at the pits that there is rarely adequate cooling water near them. But the cooling-water question will soon be serious in most large stations that are not on the sea coast, for few of our rivers are large enough for the 300 000-kW stations visualized in the future. The experience of the Birmingham station shows that the thermal efficiency is only slightly lowered by the use of cooling towers, and this would have small effect with a cheap fuel, while the first cost is not greater than that of appliances for obtaining cooling water from sources with a large tidal rise and fall. The positions of our central stations were chosen when distribution over long distances was expensive. Now that it is cheaper to transmit power electrically than by the coal truck, and a cheaper grade of coal can be used at the pit-head, a comprehensive rearrangement should be considered, pit-head stations being built to supply the increasing demand over all areas within an economic distance.

[The author's reply to this discussion will be found on page 636.]

NORTH MIDLAND CENTRE, AT LEEDS, 14TH FEBRUARY, 1939

Mr. G. F. F. Eagar: There is no part of any of the processes by which coal is won that may not, under certain circumstances, be laid under suspicion as a possible cause of a colliery explosion. I have seen runaway tubs on a steep incline cause great flashes of light that would undoubtedly have ignited an inflammable mixture of firedamp and air had one been present; electrostatic sparking can be produced where compressed-air pipes are in use; and the friction of picks on iron pyrites and ironstone, so frequently met with in coal seams and their associated strata, can produce sufficient heat to ignite firedamp under certain circumstances. These are merely three of the many possible causes of disasters by explosions in coal mines which have not always been considered in the past, and in many cases an undue amount of suspicion has been cast upon electricity and disaster attributed to it solely by deduction without any solid basis of fact.

Electricity is an almost ideal source of power for practically all mechanical operations in coal mines, but the drilling of shot-holes is not yet covered by it in the great majority of cases, since the present type of electric drill is useless when iron pyrites is present in the coal and when ironstone occurs in the roof of a coal seam. The alternative of using in-bye electrically-driven air compressors is costly, since it will be found that a compressor of 140 cubic ft. of free air per minute capacity will not supply more than three air hammer drills of the size commonly used at the coal face: an electric motor of 40 h.p. is required to drive a compressor of this size, and a system of this type is very far from being economical.

There are two factors that may largely operate against the complete electrification of collieries, or the greater degree of co-operation between public supply companies and colliery companies, namely the increased production at collieries of refuse from coal-washing plants of relatively high ash content, high moisture content, and finely divided; and the equity of terms at which colliery companies can purchase power from public supply companies, and the remuneration to be paid to colliery companies for such power as they may supply. It is true that at times supply authorities find colliery companies difficult customers, since they not infrequently have poor load factors and low power factors, but public supply companies do not seem at all prepared to encourage good load factors and high power factors by offering any inducement to colliery companies to improve their conditions of usage in this respect.

Every industry calls constantly for some degree of improvement in efficiency, and the effect of this on colliery companies is the demand for closer grading and a higher degree of cleaning of the products: this has resulted in an increased production of low-grade products, mostly with relatively high ash content, which at the present time have no sale, least of all to power-supply companies. At many collieries this inferior coal is burned at the colliery in special furnaces for power production, and, having regard to its poor quality, it is burned relatively efficiently. At the present time public supply companies cannot burn this fuel and show little or no disposition to adapt their plant to do so. Unless they make some effort in this direction there may well be in the near future some reversal of the drift towards complete electrification of collieries, since stocks of this low-grade fuel are steadily accumulating at the larger collieries, and they may ultimately be forced either to generate their own electrical power entirely, or to replace some electrical surface plant by direct steam power.

Mr. W. B. Woodhouse: On the point of safety, the statistics which the author quotes do not justify electricity being made a scapegoat. If there is an accident there is a tendency in some quarters to say that it must be due to electricity. But there are many other causes of explosion which cannot be traced, and some, I think, about which we know very little.

In the application of electricity in mines we have come to a stage of high specialization, and in the production of electricity by authorized undertakers the same specialization has taken place. The figures quoted by the author as to the relative consumption of coal per unit tell their own tale as to the advantage of centralized production of electricity, and I agree with him about the desirability of very close co-operation between those who produce coal and those who use coal to produce electricity, as their interests are similar in many respects.

Major D. H. C. Briggs: The author refers on page 599 to " the responsibility of a colliery manager." In this instance I speak on behalf of colliery managers as President of the National Managers of Collieries. I do want to stress the matter of responsibility of the colliery manager. Quite obviously it is for the manager, who has to take the responsibility by statute, to decide whether or not he shall take the risk of introducing electricity. That, perhaps, may be one of the reasons why the development of electricity does not progress as fast as the author thinks it should, having regard to the amount of machinery that still remains to be electrified. We have to realize there are many places where electricity can only be used if it is practically certain that nothing can go wrong with the plant and render it unsafe.

Turning now to the issue of certificates, I feel that the general public may be misled on that matter. The certificate is a certificate of a type, and it depends on the colliery staff to ensure that the plant remains safe. It is that point which makes certain managers hesitate to install electrical plant throughout.

I need say very little about " safety regulations " which are referred to on page 604, because I believe The Institution will have something to say about the Report of the Royal Commission when it learns later how, in fact, the Report may affect the production of the right type of plant for use in mines.

On page 607 the author refers to the fact " that a saving of 50 or even 100 % in the cost of power may mean no more than a very small saving per ton in the cost of coal won." When some of the facts are known, I think it will be obvious that the price at which we can purchase power at the pit-head from a power company may have a very significant effect on the profits. In 1938, various pits had the following consumptions per ton: $8\frac{1}{2}$ kWh, $26\frac{1}{2}$ kWh, $15\frac{1}{2}$ kWh, and $17\frac{1}{2}$ kWh. Now, obviously, if 1s. a ton is assumed to be the profit at any pit, a variation of 0·6d. or 0·3d. per kWh will certainly make a big difference in the profit of those pits which use a very large amount of electricity. The point is that whether we buy power, or generate it ourselves, we have to run our own underground transmission lines. The power company must compete with the price at our own generating station. For various reasons we can and do use fuel which others will not purchase from us at the present time.

The last thing I want to refer to is the explosion at Markham Colliery and the degree of mistrust of electricity that exists in the minds of miners.

Stone dusting, which is referred to in the paper, was originally based upon the pioneer work of the late Sir William Garforth. In this district we have, in general, continued to use the type of stone dust that he used in his experiments. I believe that the large explosions which have taken place lately have been due to a large extent to a departure from his work. I think it can be shown that other types of stone dust have proved very uncertain and have failed to prevent the spread of the explosions which have taken place in certain cases. These recent large explosions can, so far as I am aware, be attributed in every case to the use of types of stone dust other than those advocated by Sir William Garforth. I think that by using new types of stone dust we have seriously disturbed the confidence of miners and that this will take a great deal of restoring. I believe we have tried to follow in the practical field too hurriedly the experiments carried out in the laboratory, without testing them sufficiently underground, and I am rather afraid we have made a retrograde step.

Prof. F. Stuart Atkinson: The author refers to accidents in mines. It is the practice of the Divisional Inspectors of Mines in their annual reports to prepare a sector diagram showing the relative proportion of accidents. Year after year it is shown conclusively, by the size of the sector, how remarkably small is the proportion of accidents due to electricity. The same applies, incidentally, to shot-firing. Yet we constantly find objection being raised to the use of both shot-firing and electricity. The records show, however, that shot-firing and electricity are responsible for only a very small proportion of accidents in mines. Without electricity and without shot-firing I am afraid the standard of living of miners and the mining industry itself would not be as high as it is at present. This is one of the great benefits we derive from the use of electricity, and a debt to that industry we ought not to forget. I am sorry to say that it is not always remembered.

I was very interested in and endorse all that Major Briggs said about the extension of the use of electricity into parts of the mine where a colliery manager does not want it. That is a foolish hope. Electricity and compressed air are both of service to mining engineers, and I am of the opinion that, the record of electricity being good, every step should be taken to maintain it at its present standard which it has held for many years. If compressed air were replaced by electricity in any part of a mine where there is a liability for outbursts to cause accumulations of gas, I think a dis-service would be done to electricity. It is better to use compressed air.

I was interested in the author's forecast of the future and his prophecy of 90 per cent mechanization. If the term mechanization is interpreted to include coal " otherwise mechanically transported," then that figure is reached to-day, because most coal in a mine is at some stage mechanically transported. If reference is made to machine mining, however, I venture to suggest that it will be a long time before that figure is reached. In the last Divisional Inspector's Report for this area the proportion of machinery used showed a slight increase, but the output per man showed a decrease. There is no virtue in using machinery itself in the task of getting coal unless an increased output is obtained. There are seams that lend themselves to mechanical mining, and there are seams that lend themselves to the old-established system of hand getting. It is not unknown for a machine mining pit to change over to hand mining, with greater economy.

I was interested to hear references to the early flameproof tests at the University of Sheffield. I was for a short time associated with those tests and I recollect that there were many claims for gas-mantle breakages in the neighbouring houses when any electrical apparatus failed to pass.

With regard to the slides of early coal-cutting machines, I believe that the first electric cutter was put into use at a colliery near Leeds. This coal-cutter was first driven by an endless rope operating a pulley on the cutter. Occasionally the rope came out of the pulley and knocked out the props on the coal face. The mining engineer at that colliery sought the advice of an electrical engineer, who added to the coal-cutter an electric motor. This, I believe, was the first electric coal-cutter in this country and, probably, in the world. Can the author give me any information with regard to it?

In my time I have criticized many of the regulations issued under the Coal Mines Act, and I have heard a good many other people do so. I can only say that the regulations appertaining to the use of electricity in mines have been the least criticized of all.

Mr. H. Heap: I am connected with a colliery that is electrified throughout. The total horse-power of the motors is nearly 6 000, of which 3 000 is used underground. As a matter of interest, the fan consumes roughly $3\frac{1}{2}$ million units per year, i.e. one-third of the total consumption. I agree with the author that, as the situation now exists, electricity in mining is very well established, and, whether we like it or not, its withdrawal would result in closing down many pits, especially those pits that are dependent for their output on thin seams only. I know some colliery managers who say they would not have electrically-driven face machinery at any price. I find the bulk of their output is obtained from some thick seam which can be operated successfully by hand. I am of the opinion that when these thick seams are exhausted those managers will be forced to use electricity. The modern tendency of collieries is to take large areas of coal to be worked from pit shafts, which involve longer lengths of roadway over which power has to be transmitted. There is no question of the advantages of the transmission of electricity under those conditions.

The author refers to the necessity of gaining the confidence of the miners. The obvious answer is we must fight ignitions of firedamp. A good deal depends on whether the men have been brought up with, and accustomed to, electricity. In some of our thin seams the men have started as boys—as I did—in a partly electrified pit. The miner and his representative must have the same confidence in electricity as they have in a safety lamp. I see no reason why they should not have, as the flame in a safety lamp is only protected by gauze, glass, and sheet metal.

There is room, I believe, for a better type of mining electrician. Some of them to-day do not realize the importance of maintaining a flame-proof enclosure. I have known cases where they have taken the covers off switchgear and not cleaned them before replacing them. I think that some simple form of examination should be passed by a colliery electrician before he is termed competent; it would be one way of improving his status and increasing his wage.

Underground lighting from mains is mentioned in the paper, but I do not see much hope of its being adopted so long as we have men with portable lamps. Colliery managers will not force such forms of lighting or try them. I am entirely against lighting from the mains because we have so much equipment at the loading points.

In my opinion joint boxes should be designed differently and be streamlined. Only yesterday a piece of shale less than half an inch in thickness dropped from the roof and cracked a joint box. The lid went in and caused a fracture.

I think that about 40 % of the total number of accidents are caused by trailing cables. The accident rate is, however, as Prof. Atkinson mentioned, very low. I think we ought to aim at the result obtained in Yorkshire for the year 1937. Out of the total accidents, fatal and non-fatal, in Yorkshire for 1937, 49·7 % were due to falls of ground. I am of the opinion that if electricity were withdrawn from the coal face and compressed air substituted the accident rate due to falls of ground would be increased. The reason is that compressed-air machines are noisier than electrically-driven machines, and the miners would not hear the first movement of ground falling. The pneumatic pick would follow if compressed air were forced on us. If it were employed throughout the coal field as the sole cutting tool I am of the opinion that the health of the miner in 10 years' time would be very poor.

Mr. C. F. Dyer: I wish to offer some comments in regard to the author's forecast of future development, and to suggest some reasons why his dream of seeing the last colliery winding engine removed in 10 years' time is unlikely to be fulfilled.

We might well start with the question of the methods which should be adopted for the production of compressed air, for, after studying the recent report of the Royal Commission on Safety in Mines, I think the future use of electricity will be retarded and restricted, and compressed air will undoubtedly be used to a still greater extent for face work in coal-cutting, conveying, drilling, and pumping.

In view of the low efficiencies obtained, even in modern apparatus used for converting the energy in the compressed air to mechanical work, it is essential that the cost of production of this medium shall be kept to a low figure, and if we are going to use electrically-driven compressors either at the surface of the mine or, as the author suggests, inbye, placed some distance back from the coal face, then the price per unit will indeed have to be very low to compete with the steam-driven reciprocating or turbo compressors, using either high-pressure or exhaust steam.

There are several difficulties to surmount if comparatively large compressor units are placed underground; firstly in the construction of engine house and foundations, secondly in the provision of water for interstage cooling, and thirdly in the provision of suitable filtering apparatus for cleaning the dust-laden inlet air.

If it is realized that the compressed air required on a double-unit face with coal-cutters, face and gate conveyors, will average something like 2 000 cu. ft. per min., and that there may be 6 or more units in operation, the problem will be seen to be complicated, and the benefit of diversity factor will not be obtained as it would be if the compressed-air plant were at the surface.

In the South Yorkshire district, where large outputs are obtained from individual pits and compressed-air-driven face machinery is largely used, some collieries are producing air from steam-driven compressors at a cost of 0·75d. per 1 000 cubic ft., to equal which electricity would have to be bought at 0·3d. per unit, a price slightly higher than the cost of production of electricity at the collieries in question.

Turning to the question of electricity versus steam for winding, I submit that the price per unit would have to be fixed at ½d. or less to compare with steam costing 1s. 3d. per 1 000 lb.

Ultimately steam is the base from which the power has to be derived, whether it is produced by the supply authority or the colliery company, and although it is agreed that the supply authority will obtain a larger proportion of energy from the steam produced, owing to the utilization of high pressures and large and efficient generating units, the fact remains that the actual cost of production per 1 000 lb. of steam at a super-power station is, as far as I can discover from published figures, approximately 1s. and upwards.

Many colliery companies are producing steam from a very low-grade fuel at less than this figure, and there can be no incentive for them to buy power from a supply authority unless some means can be found for getting rid of this product at a price for which it is now charged as boiler fuel. The question of the disposal of this inferior fuel is a very important one. The fuel consists principally of material extracted in the process of screening and washing, and must either be burnt under the colliery boilers or subjected to a further and more expensive process of cleaning to get rid of its ash or moisture content, as the case may be, and even when this is done I doubt whether it would be possible to obtain a regular market for it at a price which would cover the cost of this extra treatment.

If, however, a co-operative scheme of working between the collieries and the supply authorities, such as is envisaged by the author, could be set up whereby this low-grade fuel could be disposed of, it would be a great inducement for colliery companies to abstain from replacing or extending their steam plant and to purchase electric power from the supply authority. I feel confident that if the colliery companies can sell to the supply companies the fuel they are using they will do so. Many collieries would only be too glad to avail themselves of a partial supply from outside sources, instead of extending their own generating plant, if they could be certain of obtaining it at a fairly low average cost which would not suddenly be raised by 100 % or more because the kVA demand was considerably increased by a few hours only.

Major H. M. Hudspeth: I admire the author's defence of an admitted danger. Whilst the progress made since the early days has been great, the use of electricity in mines is still potentially dangerous, and it has even been suggested that the attempts to ensure safety have led to carelessness. As someone said to me the other day, "electricity was treated with respect 30 years ago and the persons using it did not have any false sense of security."

There is one important point in the paper to which I should like to refer. I agree with the author as regards the desirability of co-operation between the mines and the electricity undertakings, and I think I am right in saying that this co-operation is well exemplified in this district by the arrangements which exist between some colliery companies and the Yorkshire Electric Power Co.

Some of the author's figures are striking. He gives 5 500 million units as the estimated total consumption of all the collieries if wholly electrified, and states that they use 12 million tons of coal for power production, whereas 14¾ million tons of coal produce 22 011 million units at public electricity supply undertakings. On this basis the collieries would appear to be wasting over 8 million tons of coal a year, but I doubt if the figures are comparable, for some of the coal used under colliery boilers is by no means as good as that used at public generating stations. However, the margin is great, and it is right that we should utilize our fuels in the most efficient manner possible. In this connection the advantages of electricity are obvious, particularly for power transmission; but I suggest that the author is optimistic as regards possible future development, apart from stating an aim. Admittedly, safety is, in practice, a relative term, and I wish it could be definitely stated, as regards the use of power in mines, that the most economical form is the safest. When this stage is reached the author's hopes and aspirations will be well founded.

Mr. R. L. Gaunt: In giving details of the electrical equipment of 30 years ago, the author refers to the lack of status of the colliery electrician and the low wages paid at that time. In my view the position is somewhat similar to-day, but I am of the opinion that in a few years a very great change will take place and the electrical engineer will have the status of chief engineer. In the author's statistical review of the last 25 years (Table 2) it is of interest to see that, whereas in 1912 38 % of the total horse-power was installed above ground, this increased to 47 % in 1937, and that below ground the figures are 62 % and 53 % respectively, indicating that the increase is largely due to the additional mechanical handling of coal in the pit. It would be interesting to know the number of mines using a public supply of electricity in 1912. For the collieries in Yorkshire the latest published figures show that, of the 239 mines at work, 169 (65 %) are using electricity and employing about 306 000 h.p. Of these approximately 60 % use a public supply of electricity.

On the subject of future development and for comparison with the author's figures, I find that with the 2·2 million h.p. of motors installed the consumption is approximately 3 000 million units a year.

The author gives a figure of 5 500 million units as the annual consumption if the whole of the collieries in the country were to be electrified. Taking the 1937 output of 240 million tons per annum this represents an average figure of 23 units per ton of colliery output, and I estimate that this would represent a total of $3\frac{1}{4}$ million h.p. installed, without allowing for any further mechanization, and I agree that at least a further 1 million h.p. has yet to be converted to electric drive.

In assessing the value of a public supply of electricity compared with the production of power at a colliery, it is sometimes suggested to me that the generation costs by means of mixed-pressure turbines are from 0·1d. to 0·2d. per unit. This is a misleading basis on which to make the comparison. If, for instance, the winding engines and other engines on the surface exhausting to the turbine became less efficient and used more steam, this would even further reduce the cost of generation. I consider that the correct method of valuation is to take the total cost of power per ton of colliery output and not the cost per unit generated by exhaust steam without regard to other expenses. If these costs are correctly set out, commencing at the boiler house and including the power-house costs and those of the other steam plant on the surface, then it is a simple matter to arrive at the cost of power per ton of output. From a consideration of the duty of existing steam drives, an estimate can readily be made of the cost of power per ton of output if those duties were performed by electric drive, and the balance after making allowance for the new capital involved will generally be in favour of electrification.

I should like to quote the following example confirming my view. A colliery company winding by steam and using other surface steam-engines, but with the remainder of the plant electrically driven from a public supply, considered that by the installation of a mixed-pressure turbine they would be able to replace the public supply and reduce the cost per unit to about half the price paid for the public supply. A comparison on the lines I have suggested, however, disclosed that with an electric winder and the other surface engines converted to electric drive, the use of the public supply effected a saving of several pence per ton in colliery output as compared with the alternative of the installation of a mixed-steam pressure turbine and the retention of the steam plant. As a consequence the colliery company decided to scrap their boiler plant and install an electric winder.

I support the author's forecast that co-operation between the supply authorities and the colliery companies will be extended. This principle of co-operation is already being acted upon in Yorkshire, and colliery companies are using the power company's comprehensive systems as a means not only of conveying electricity to the collieries but of conveying from them the surplus power the collieries have available from time to time. The basis of these joint schemes is that the benefit of co-operative utilization is divided fairly between the two parties to the arrangement.

The argument is advanced that the colliery power-plant consumes "unsaleable coal," but developments are such that no class of coal with any substantial heat value can be regarded as unsaleable. If in any particular case low-grade fuel is used in a colliery power-plant instead of in a large power station, that power plant should be linked to the general supply mains.

In recent years the use of slurry has increased at many collieries which hold the view that slurry can only be burnt on colliery boilers and is unmarketable, but the firing of such fuel in relatively small boiler plants does not secure the maximum efficiency.

The power company, by reason of their large boiler plants and specialization of power production, can use all fuels to obtain the most economical results. Surplus coke-oven gas is also used at a number of collieries for steam-raising purposes, and the remainder is sold to the gas undertakings, but owing to the variable demand for gas, particularly during week-ends and holidays, the quantity supplied varies and when not required must either be flared at the colliery or burnt in place of solid fuel—admittedly an inefficient overall method of operation. Here, again, co-operation with the power company would utilize this surplus gas or waste heat continuously.

If a colliery company uses low-grade fuel and waste heat in an isolated power station at the pit, the plant installed has a capacity for an additional output which is not utilized, because the maximum load varies from time to time and cannot be accurately predicted. Power requirements vary from hour to hour, and at night, week-ends, and holidays, are usually low, and it is only during the coal-winding shift that a local plant is working at an economical load, but even during this period the load is variable.

It is found in practice that the power requirements of a colliery amount to 40 % of the electricity which could have been generated, and the same reasoning applies to the utilization of waste heat. Under a joint arrangement the supply authority would sell to the colliery company to the extent of their requirements and supply the surplus to the supply authority's other consumers. The advantage to the colliery company would be in having the supply authority's other stations as standby to their requirements. No special plant need be provided at the colliery, and there would be economical use of capital, a market for all waste heat, cheap electricity, and reliability, which cannot be assessed in terms of money value, and the advantage to the supply authority would be the possibility of obtaining cheap fuel.

Mr. J. Mann: I am of the opinion that many of the fires which have occurred in mines would not have taken place if sensitive leakage protection had been installed. The idea seems to be prevalent in some quarters that such protection is difficult to apply to d.c. plants, but I can confidently say that very sensitive leakage protection can be obtained for such plants.

Regarding the accident rate and the psychology of the miners towards it, I wonder whether it is really the miner himself who is so apathetic to the use of electricity or whether when there is an accident involving loss of life due to electricity it is not rather political interference or newspaper talk that causes so much of that trouble.

The author gives it as his opinion that the reduction of accidents is largely dependent upon a high standard of maintenance; and reference has been made in the discussion to the poor quality of electrical maintenance provided by colliery electricians in general. As a representative of the Association of Mining Electrical

Engineers, I should like to point out that the Association regularly holds certificate examinations which, to a great extent at any rate, prove the ability of the electricians in charge, and it is suggested by the Royal Commission that colliery electricians should be so certificated.

Coming now to the question of privately-owned generating plant versus the public supply, I should like to quote in Table D some actual figures from a number of collieries, some generating their own supply and some purchasing it from various undertakings.

Table D

Colliery	Source of supply	Annual consumption	Cost per unit	Remarks
		kWh × 10^6	d.	
A	Private	0·5	0·23*	Exhaust steam mainly
B	Public	1·3	0·648	
C	Private	0·9	0·58	Reciprocating sets
D	Public	3·5	0·42	
E	Public	4·5	0·486	
F	Private	4·3	0·3275	
G	Private	8·0	0·224	
H	Private	19·75	0·2022†	Washing slurry only
I	Private	40·0	0·34‡	
J	Private	52·5	0·23	
K	Private	53·5	0·32	
L	Private	82·5	0·32	Gas

* Depreciation omitted.
† Includes 0·0737d. for depreciation.
‡ Includes very heavy depreciation charges on spare plant, switchgear, and overhead lines.

Most of the collieries in Table D use a considerable quantity of low-pressure exhaust steam. I think that the figures leave no doubt that the private supply is the cheaper. I expect to be told that those collieries which produce their own power have omitted to include a large proportion of their costs, but I would point out that coal owners and colliery managers are business men who would go very carefully into the question of costs.

A suggestion has been made that low-grade fuel should be supplied to power stations, but I have not yet seen one that burns slurry. It is also suggested that it is often not worth burning. The alternative is to throw it on the scrap heap, in which case money will have to be spent in putting out the fires due to spontaneous combustion.

It is with a feeling of shame that I read that 12 million tons of coal were burnt under colliery boilers for generating power, as against 14¾ million tons by supply undertakings, especially considering the meagre amount of power used by the former. Probably 40 % of the coal burnt was ash.

In regard to the possibility of co-operation, there is a splendid opportunity in this district. Many of the collieries have in operation transmission schemes which could be linked up with some central body and may even be supplied from the grid. However, I feel that the cost of electricity will have to be considerably reduced if that is to be a success, otherwise I am afraid we shall have to continue to burn, say, 7·2 million tons of coal and produce 4·8 million tons of ash.

Mr. G. A. McNeal: We have heard a good deal about the status of the colliery electrician, and one point which has particularly impressed me in the paper is the responsibility which rests on such electricians. Although the final legal responsibility may be with the mines manager, we must remember that the electrician is the watch-dog of safety in the mine. I feel that the experiences of a previous speaker with colliery electricians can hardly be taken as general, and I think that all those of us who are acquainted with the work they have to carry out are agreed that they are up against extraordinary difficulties. Anyone who is not familiar with underground conditions cannot possibly realize how considerable these difficulties are. It is of little use trying to form any comparison between work on the surface and work underground. If a fault develops in an industrial installation or on the surface of a mine the electrician works in comfort, compared with the conditions experienced by the electrician underground. When there is electrical trouble underground the electrician has first to walk possibly 2 or 3 miles from the shaft bottom, making sure he has brought with him all the tools that can possibly be required. He has to work often in restricted room, and always in a poor light. If any internal adjustment of electrical apparatus seems necessary, and if the apparatus in question is of flame-proof construction, then the electrician must remove the covers, examine the interior, make any adjustment he may deem necessary, replace all covers, and securely bolt up before re-energizing the equipment. If the adjustment has no effect, then it may be necessary for this arduous procedure to be repeated several times. Meanwhile the electrician will be surrounded by a group of miners urging him to get the power restored and giving him advice. Under such conditions there is a natural tendency for the easiest course to be followed, one which, however, may also be the most dangerous. One has heard of electricians making adjustments with power on and flame-proof covers removed. I think, therefore, that it is important we should recruit the right type of man to be our watch-dog. We require a man not only with sound technical ability but with character and determination who is able to deal with emergencies underground without allowing himself to be pushed into taking risks which may endanger the lives of those working underground. I very much doubt whether the opportunities offered to colliery electricians are sufficient to attract the type of man we need. Many sound young men hesitate to embark on a career as a colliery electrical engineer, because they feel that remuneration and status are both lower than they should be.

Touching the question of safety in mines, it is very encouraging to read on page 605 that over a period of 10 years electricity has been responsible for only 2½ % of the total fatalities. I think this should be more widely known, in view of the varied reports we get in regard to accidents caused by electricity.

Prof. D. Hay (*communicated*): I think that the author gives insufficient credit to the colliery companies for the part they have played in developing the use of electricity for general industrial purposes. The collieries certainly made a commencement with industrial application of electric power about the year 1883, as the author states. Actually in the same year my grandfather was responsible for a small pumping station underground at Nostell Colliery, and electricity appears to have come fairly generally into use between 1883 and 1885. Again, the author does not state that the Parsons turbine put down at Acton Hall Colliery in 1898 was the first alternating-current turbo-generator in the world.

In the development of colliery electrical equipment the mining engineer has played a substantial part in developing the design of various types of machinery in use. In fact, the mining engineer rather than the manufacturer has taken the lead, and many mining engineers will recollect the difficulties that they have had in persuading manufacturers to modify the design of electrical machinery to suit underground conditions. There are, of course, exceptions, and certain manufacturers have led the way in this development.

As regards the safety aspect, I think credit must be given in the first instance to the Mines Department, commencing with the author's own work. The mining engineer of 30 to 40 years ago had not had the training required to appreciate what had to be done to render apparatus intrinsically safe; such knowledge was in the possession of a few specialists who pioneered this aspect of the problem. In this way the mining industry owes a great deal to the Mines Department for the part it has played in developing the design of safe apparatus, and also to the work of individuals such as Prof. Thornton and Dr. Wheeler.

In 1921, when I was Professor of Mining at Sheffield University, Dr. Wheeler and I discussed the possibility of developing a practical test to prove the safety of various types of apparatus. We built and put into operation the first large explosion chamber, and granted many certificates which were known as Sheffield University Test Certificates. This work was carried on at Sheffield University until the testing was quite properly taken over in 1930 by the Mines Department. I have lively recollections of the difficulties we had at that time in persuading many manufacturers to modify their designs. Failures of apparatus on test were not uncommon, frequently with disastrous results to the windows of the Mining Department and surrounding houses.

To-day it is fair to say that there is efficient electrical apparatus available for practically every task underground, and it is beyond doubt that modern flame-proof apparatus, properly installed and maintained, will not give rise to danger. The principal fear of danger in the minds of mining engineers to-day arises from the cable rather than from the apparatus, and even with the most modern cables fully armoured and protected by leakage protection, etc., the risk of open arcing is, although rare, sufficiently disturbing to cause mining engineers seriously to consider the position. Personally I believe that cables should not, unless absolutely necessary, be carried on haulage roads at all, as the principal risk is from fracture of the cable in some kind of haulage smash. Unfortunately, leakage protection does not seem in all cases to isolate the circuit before the cable is punctured by the arcing, probably because a short-circuit occurs from phase to phase and considerable damage is done before the fault finds an earth connection. It is admitted that the risk is probably small with modern cables, but certain recent occurrences have given rise to fears that a cable might be responsible for direct ignitions of coal dust.

There is, in fact, a strong feeling amongst mining engineers that where the risk from coal dust or gas is appreciable electricity should not be used underground except to a limited extent, and that all coal-face operations should be carried out by compressed air. This tendency is encouraged by the high capital cost of modern switchgear, motors, and cables, together with the much higher standard of maintenance required to keep them in safe condition, so that the additional capital and maintenance charges involved largely wipe out the advantage which electricity has in consequence of its more efficient use as compared with compressed air. Recent legislation, and the new legislation which is now threatened, all tend to make the responsibilities of installing electricity underground exceedingly great. I am convinced that the use of electricity underground will tend to diminish rather than increase in the future: here I differ from the author.

I cannot altogether agree with the author's forecast of future development, and his argument that all privately-owned generating plant should disappear. I have heard this argument stated many times by public supply electrical engineers, who claim that colliery companies in assessing the cost of their own power as 0·16d. to 0·3d. at their own busbars are understating facts. This, however, is not so, and it is beyond all question that when all possible charges, including a proper proportion of standing charges, are made against the colliery power station, a figure of ¼d. per unit at the colliery busbars is easily achieved. Against this it is rarely possible to-day, certainly in the Midlands, to obtain a quotation for power delivered to the same busbars for less than ½d. per unit. This figure has diminished little, if at all, during the past 10 years and shows, if anything, a tendency to increase again to-day. In fact, it may well be asked what the grid is doing so far as the cheap supply of electricity is concerned, because its benefits have certainly not yet reached the companies with which I am connected.

It must be remembered that the bulk of the fuel used to-day at colliery boilers is low-grade material, much of which would otherwise find its way on to the dirt tip. Here again public authorities are putting pressure on colliery companies to prevent them from depositing combustible material on the dirt tips, and the collieries are therefore compelled to find some method of destroying it themselves. It is material that cannot be washed or cleaned to a commercial standard, and the only outlet appears to be the colliery boiler plant. This is, in my opinion, the predominating factor and will, unless substantial changes in the position occur, lead to a continuation of steam-raising for general purposes at collieries, and will check any development in the way of the greater use of electricity.

There remains what is probably the best solution, namely co-operation between the public supply companies and the collieries, and I have done this for many years with, I think, what may fairly be claimed as advantages both to the colliery company and to the power supply company.

Finally, it must be remembered that with colliery generation of electric power electricity is available at the colliery busbars for the mere cost of running a steam-driven alternator obtaining its steam from low-grade fuel worth only a few shillings a ton at the most. Efficiency is of little interest. On the other hand, the power company has to bring its power to the same busbars by a transmission system extending usually over many miles of country, and the transmission cost is probably well over $\frac{1}{3}$d. per unit before the electricity arrives at the colliery at all. How can the super-power station, many miles away, expect to compete with colliery generation?

THE AUTHOR'S REPLY TO THE DISCUSSIONS AT LONDON, NOTTINGHAM, NEWCASTLE, MANCHESTER, BIRMINGHAM, CARDIFF, LIVERPOOL, EDINBURGH, AND LEEDS

Mr. R. Nelson (*in reply*): I may perhaps first repeat that one object of the paper was to have recorded in the *Journal* a brief account of the circumstances surrounding the early use of electricity in coal mines. On the whole the record is one of marked technical progress and of difficulties of various kinds, not all of them, as yet, completely overcome. There was also the idea that a backward glance might well be of use to those concerned with future development.

Apart from the discussion before The Institution, the discussions before the Local Centres, notably at Edinburgh and Birmingham, were very informative and interesting from the standpoint of the early use of electricity. The interest aroused at nearly every Local Centre owed a good deal to the presence, by invitation, of members of the Institution of Mining Engineers and of the Association of Mining Electrical Engineers. Many contributions had in them a strong vein of reminiscence requiring, here, no more than due appreciation and acknowledgment.

The number and variety of the questions raised leave me with the feeling that to deal with them all, even if I were qualified to make the attempt, would occupy too much space. The intention therefore is to name the more important of them and to offer a few words of comment on each in turn. Broadly, the discussions covered (*a*) the historical aspect; (*b*) the safety aspect; (*c*) private generation versus the grid supply; (*d*) future development, including the possibility of a measure of co-operation between coal and electricity; and (*e*) the status of the electrician and the attitude of the miners towards electricity in coal mines at the present time.

From the historical standpoint one omission was early noticed, namely the early use of the concentric system of distribution as introduced and widely used by the late H. A. Mavor, more particularly in Scotland. This is an omission only to be acknowledged by the confession of an oversight. The concentric system was safe and served very well the period of its popularity in the 1890's and perhaps a little later. The discussion at Nottingham brought to light that electricity was used for underground lighting at Pleasley Colliery, in Derbyshire, as early as 1882 and that the engineer responsible for the installation was Col. R. E. Crompton. In addition to those who were mentioned as pioneers in the use of electricity in mines should be added the names of Mr. Ll. B. Atkinson and his brother, the late C. W. Atkinson, and the late W. C. Mountain of Newcastle-upon-Tyne.

Speaking at the discussion before The Institution, Mr. Woodhouse said he thought that scant credit had been given to the power companies for having made available a supply of current in the coalfields from an early date, and for having made the grid transmission system possible. It was, of course, the power company who introduced 3-phase working to the collieries as to industry generally, but I did not notice any great enthusiasm for the grid amongst the power companies at the time of its inception 11 years ago. It is, nevertheless, true that it was the wide distribution areas of the power companies, which, when linked together, seemed to create the grid almost in a night, and in so doing made an adequate supply of electricity available for all purposes in many places where such supply had not hitherto been available. Unfortunately no complete statistics are available of the extent to which the collieries have taken advantage of the public supply, but an interesting point emerged at the discussion at Newcastle, namely that of all the winding machinery in the Durham and Northumberland coalfield more than one-half is now electrically driven by current purchased from the North-Eastern Electric Supply Co.

On the question of safety, since the paper was written the Royal Commission on Safety in Coal Mines (appointed in December, 1935) has reported, and almost the first result was the appointment of a Departmental Committee to consider and report upon such amendments of the existing Electricity Regulations as are thought to be desirable. At all the Local Centres speakers welcomed very warmly the suggestion contained in the Royal Commission's Report that both the colliery mechanical engineer and the colliery electrician, like the colliery manager himself, should be certificated, for the discussions revealed that the status and authority of the electrician is in too many cases below that necessary to ensure the continued safe use of electricity.

The question of private generation versus public supply was frequently referred to in the discussions, but little was said in opposition to the conclusion stated in the paper, namely that no hard-and-fast verdict is possible beyond that there are many borderline cases and that these naturally required consideration in detail. The advocates of private generation would have left a firmer impression had they remained content with the assertion that in certain areas and in cases within their own experience and knowledge, electrical energy can be generated more cheaply than it can, at present, be purchased.

They were, however, seldom content with a broad statement in that sense; generating costs of outstanding merit were constantly quoted as having been obtained from the use of "unsaleable fuel." Mr. Mann exposes the hand frequently played by the advocates of private generation when in Table D he gives the units generated but makes no mention of load factor. Of nine instances in which he gives the cost per unit by private generation, only two include anything to cover depreciation of plant, a necessary item if a correct comparison is to be made with the cost of energy obtained from an outside source. Prof. Douglas Hay supports Mr. Mann. He states that "¼d. per unit at the colliery busbars is easily achieved," again without any reference to load factor, whereas, he adds, it is "rarely possible" to obtain a quotation for power from the public supply in the Midlands "delivered to the same busbars for less than ½d. per unit." In these circumstances Prof. Hay asks, very pertinently if the position is as stated, what the grid is doing to benefit the Midland coalfield. But in the end he relents by remarking that he has found co-operation with the power supply company useful, and his final conclusion is that co-operation "is probably the best solution."

In this conclusion he was almost, if not entirely, alone among representatives of the coal industry, for though many electrical engineers, notably Mr. Woodhouse and Mr. Howles, supported the idea of co-operation between the coal and power-supply industries (for which, of course, no originality is claimed), no representative of the coal industry made anything that could be described as a serious contribution in its favour. The kind of co-operation Prof. Hay envisages is part only of the wider scheme of co-operation outlined in the paper. It is perhaps best described in the contribution made by Mr. Fennell, who drew attention to a "reverse grid system" in operation near Liége in Belgium. Here the public electricity supply authority purchases from collieries and steel works about 75 per cent of the energy it distributes for general purposes. This measure of co-operation was advocated some years ago by Prof. F. G. Baily and has of course some examples in Great Britain; its chief merits are the avoidance of waste and the use of low-grade fuel on the spot where it is mined.

The lack of co-operation between those who produce coal and those who produce electricity, using coal as raw material, compared with the extent to which they could assist each other with advantage, not only to themselves but to other and wider interests, is remarkable. In my opinion, unless the principle of co-operative effort is more widely recognized than now, there is much greater danger than otherwise there would be from foreign competition, especially in these days of intensive nationalism and bounty-fed imports. Where a clear opportunity arises the technical and commercial ability we may claim to possess should be used to further interests wider than sectional interests; and here perhaps the subject may be left for the further consideration of the parties immediately concerned.

On the subject of future development, the statement is made in the paper that there remains 1 000 000 h.p. of driven machinery at the coal mines still to be electrified. Basing upon recent progress it was humorously suggested that the last steam winding-engine might be found in South Kensington Museum in 10 years' time. This statement was persistently treated as a considered forecast, but that was not of course the intention. Ten years ago there was probably some 1 500 000 h.p. of driven machinery still to be electrified, and if 500 000 h.p. remains 10 years hence, that is likely to be nearer to what the then situation will be; for much of the electrical horse-power added each year is either new or is used to replace hand or pony labour. Even the youngest member of The Institution is unlikely to be called upon to visit South Kensington should he wish to see a steam winding-engine.

The question of the goodwill of the miners has been left to the last. One hope which arose during the preparation of the paper was that of assisting the growth of confidence amongst the miners. It is perhaps too much to expect a welcoming attitude on their part, for they instinctively oppose anything which displaces hand labour, but the industry should seek to establish with the miners the position that since mechanical power must necessarily be used more and more below-ground for economical reasons, the best way to transmit it, and for the most part to employ it, is in the form of electricity. The record of electricity from a safety standpoint was discussed very fully, some speakers thought disproportionately, but, closely examined, it is on the whole very encouraging. These two considerations, the usefulness of electricity, and, properly controlled, its inherent safety, will, it may be hoped, persuade the miners' leaders to adopt a more liberal and less critical attitude towards electricity in coal mines than is at present customary amongst them.

EMPIRE TELEGRAPH COMMUNICATIONS

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SUMMARY

The paper deals with the engineering aspect of Empire telegraph communications. In order that the size and scope of these communications may be realized, the author begins by setting forth the components of the telegraph operating company, showing the systems contributed by each section.

The engineering organization within the operating company is then dealt with, the training and necessary qualifications of telegraph engineers in the present service being outlined.

Returning to the general aspect of Empire communications, the main traffic routes are discussed, with details of a number of main-line circuits. Some of the engineering requirements of the flow of traffic are touched on.

Having dealt briefly with the system, the paper proceeds to enumerate the methods by which the collection and the delivery of messages are effected. The methods of signalling and the suitability of the different codes under varying circumstances are explained.

The author then presents a short history of progress in cable telegraphy. Modern methods of signal shaping, balancing, and synchronous-regenerator working on cable circuits are reviewed. Where well-known methods are in use the descriptions are brief, full technical explanations being given only where information has not previously been published except in patent specifications. The items described in detail include the capacitance magnifier, the fork relay, the automatic bias corrector, and the automatic scrutinizer.

There follow brief notes on recent progress and cable problems which are still being investigated.

A brief outline of the methods of operating the wireless telegraph circuits is given, with details of the application of regenerator working to these circuits. A description of a method of double-frequency keying of wireless circuits follows. Finally, reference is made to the effects of varying cosmic conditions on wireless signals.

(1) INTRODUCTION: COMPOSITION AND SERVICES OF OPERATING COMPANY

On the 29th September, 1929, the telegraph communications of the Empire, as detailed below, were, by Act of Parliament, placed in the hands of a single operating company. At the same time an Imperial Communications Advisory Committee was set up, the members of which were nominated by the British and Dominion Governments. This operating company took over the systems belonging to the following companies and departments:—

The Eastern Telegraph Co., Ltd., and four associated companies.

The Eastern Extension, Australasia and China Telegraph Co., Ltd.

The Western Telegraph Co., Ltd., and four associated companies.

The telegraph operating section of Marconi's Wireless Telegraph Co., Ltd., with several subsidiary services.

The Imperial Cables, and the English end of the beam wireless services formerly operated by the British Post Office.

The Pacific Cable Board's cable system and the West Indian wireless services associated therewith.

In addition to the above, 8 other telegraph companies came under the control of the operating company. The component parts of the operating company are further detailed in Appendix 1.

In Appendix 2 will be found maps showing: (*a*) The main cable connections of the Eastern and associated companies before the merger (Fig. 37). (*b*) Other cable and landline systems incorporated in the merger (Fig. 38). (*c*) Wireless services as established by the Government and by the Marconi Co. before the merger (Fig. 39). (*d*) Wireless services opened since the merger (Fig. 40). The first two maps show how effectually the State-owned cables filled in the gaps in the network established by the companies, thus providing a comprehensive Empire cable system. The fourth map reveals that considerable progress has been made in extending both Empire and Empire-foreign services.

In addition to the main systems indicated on the maps, there are various small wireless circuits and ship and aircraft services. The cable systems in many parts of the world have been reorganized. The terminals of certain wireless circuits in South Africa, India, Canada, Egypt, and Australia are operated by local companies. Except in the cases of Australia and Canada, the cable systems in these countries are also operated by the local companies, by arrangement with the operating company. Telegraph connections also exist between Great Britain and foreign countries on certain wireless circuits operated by the Post Office. The Post Office also maintains a broadcast telegraph service on long and short wavelengths. Radiotelephony in the United Kingdom is controlled and operated by the G.P.O., but the overseas terminals in the Dominions are controlled either by the above-mentioned local companies or by the operating company. The latter also operates some colonial-foreign wireless telephone circuits, such as Bermuda–New York and Kingston–Miami–New York, these services linking up with the normal United States network and with other countries.

The operating company also handles abroad the shore end of various ship services, some of which are fitted with direction-finding apparatus. At Nairobi, Bermuda, and Bahrein, Adcock direction-finding stations for air services are in operation.

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* Cable and Wireless, Ltd.

Other activities included are the London end of radio-phototelegraph services with New York, Buenos Aires, Melbourne, and Tokio; also land telephony in Cyprus and Peru, and broadcasting in Kenya.

The present telegraph system comprises 155 090 nautical miles of submarine cable, 125 wireless circuits, and 161 overseas branches.

With regard to cable circuits, only those of most recent date are of the high-speed loaded type in which the copper conductor is surrounded by high-permeability nickel-iron alloy. The duplicate cables across the Pacific, and the duplicate Cocos–Perth cable, are of this type. Since two or more cables are already laid on all important routes, it would not be economical to replace them by one high-speed cable in which an interruption would dislocate the service.

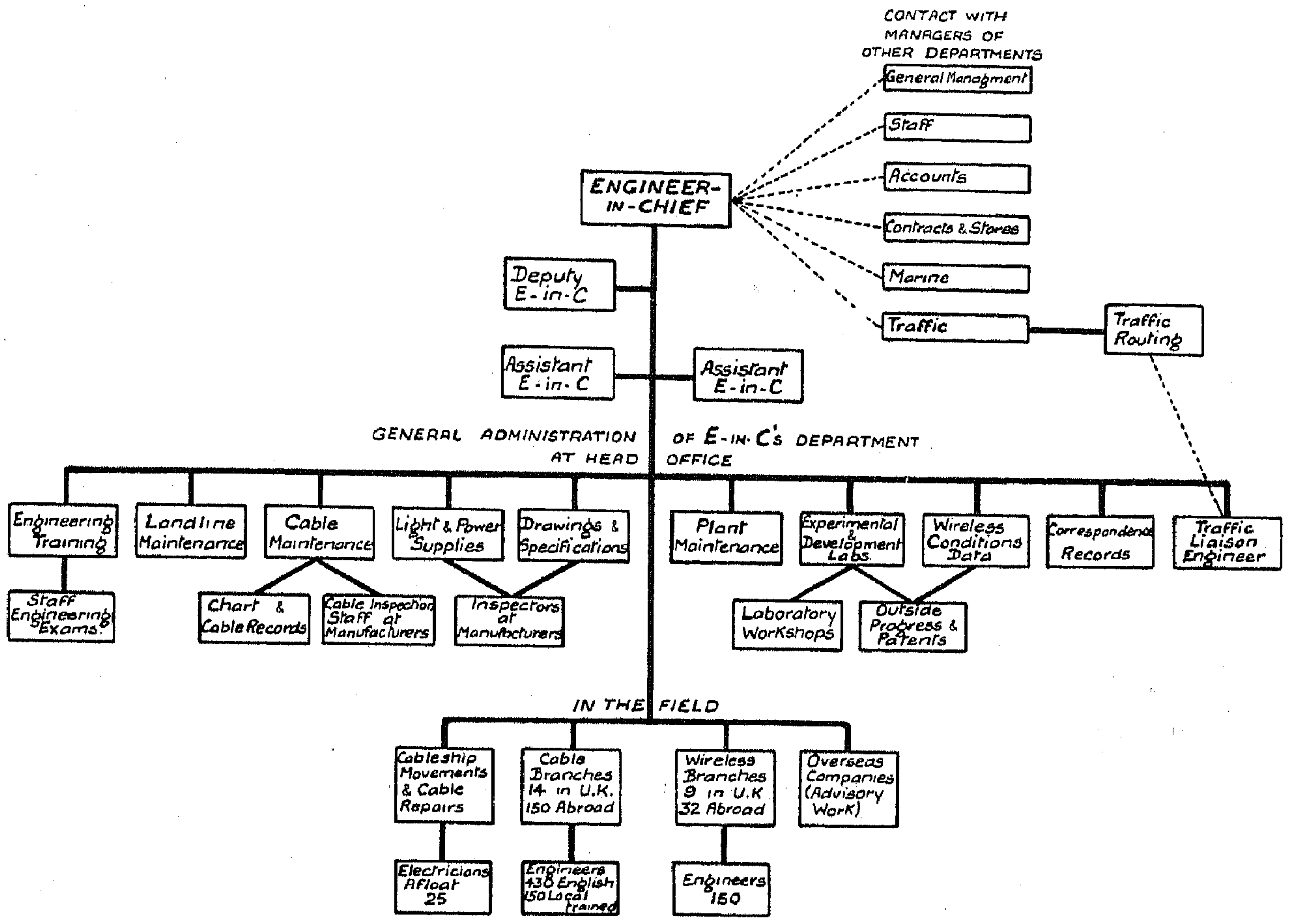
CONTACT WITH MANAGERS OF OTHER DEPARTMENTS
General Management
Staff
Accounts
Contracts & Stores
Marine
Traffic
Traffic Routing
ENGINEER-IN-CHIEF
Deputy E-in-C
Assistant E-in-C
Assistant E-in-C
GENERAL ADMINISTRATION AT HEAD OFFICE OF E-IN-C's DEPARTMENT
Engineering Training
Staff Engineering Exams.
Landline Maintenance
Cable Maintenance
Chart & Cable Records
Cable Inspection Staff at Manufacturers
Light & Power Supplies
Drawings & Specifications
Inspectors at Manufacturers
Plant Maintenance
Experimental & Development Labs.
Wireless Conditions Data
Laboratory Workshops
Outside Progress & Patents
Correspondence Records
Traffic Liaison Engineer
IN THE FIELD
Cableship Movements & Cable Repairs
Electricians Afloat 25
Cable Branches 14 in U.K. 150 Abroad
Engineers 430 English 150 Local trained
Wireless Branches 9 in U.K 32 Abroad
Engineers 150
Overseas Companies (Advisory Work)

Fig. 1.—Engineering organization.

(2) ENGINEERING ORGANIZATION WITHIN THE OPERATING COMPANY

When the cable and wireless companies were united, the problem at once arose of combining two distinct engineering staffs, one trained mainly in cable working, and the other mainly in wireless working, the obvious aim being to avoid overlapping and to make the best use of the experience and skill available in both sections under the new administrative conditions. The problem was met by retaining specialists on each class of work and by selecting a certain number of the younger men, who had shown themselves to be sound both practically and theoretically, and training them in both wireless and cable work. After a reasonable period of time it thus became possible to economize efficiently at various stations where both wireless and cable circuits were operated.

The merger brought together the two head-office engineering departments, and, for a period, duplication of engineers-in-chief and of their deputies was unavoidable. As knowledge of the capabilities and problems of the two systems accumulated, economies were effected by combining the duties of various officers. The eventual organization of the head-office engineering department is shown in the accompanying chart (Fig. 1). The heads of the department consist of an engineer-in-chief, a deputy, and two assistants. The general administration section contains staff from both services, the majority of whom have received training and experience in both cable and wireless work, though some degree of specialization is necessary in many cases. Specialization, allied to a certain amount of general knowledge, is required in most of the other sections of the department.

A number of the posts are temporary appointments; selected foreign-service engineers are appointed to the general administration and development sections of the head-office department for periods up to 3 years, in order that the maximum number shall have experience of head-office methods and that the qualifications of a number of engineers shall come under review, enabling further selection to be made when vacancies occur in the permanent positions in the department.

From Fig. 1 it will be seen that a close liaison is maintained between the traffic and engineering departments. Cable interruptions and bad wireless conditions are always setting up combinations to which the best-fitting key has to be found, by prompt co-operation between the two departments, for carrying the traffic expeditiously.

The operations of the cable maintenance department are very important; it is that department's duty to advise the engineer-in-chief of sections requiring renewal; the amount and type of cable likely to be required; and the state of stocks on ships, on shore, and under manufacture. Every repair means an alteration in history diagram, splice list, and chart. These together form a comprehensive record of each particular cable. The history diagram is a record of every renewal and repair to the cable since it was originally laid, the splice list contains the principal electrical and mechanical data of the existing cable, and the chart shows its position on the ocean bed.

The training of engineers for the service is of primary importance. The method employed up to the present is to select healthy young men who have reached or approached matriculation standard and have shown promise in scientific subjects as well as a facility for foreign languages. Their first training is in telegraph operating; during this course they also attend lectures on the fundamentals of electrical theory and receive some mechanical training. Those who do not respond to the engineering training may continue as operators, with the possibility of promotion on the administration side. Those who show engineering ability, especially on the practical side, will be given a course lasting 2 years, during which they are instructed in wireless and cable theory and are thoroughly trained in the use of all the apparatus of which they are likely to have charge. This training includes the attainment of sufficient skill to manufacture and repair any component part of the mechanical apparatus. Proficiency in cable fault and break localization is also attained.

From Fig. 1 it will be seen that contact is maintained between the engineer-in-chief and the staff manager. The staff manager is responsible for the selection, general training, and subsequent movements of staff, including engineers. In view of the great distances involved, the importance of interchangeability of staff in making the movements of personnel as economical as possible will be realized.

(3) ROUTES

Although it is primarily the work of the traffic department to regulate the routes and the flow of traffic, the engineers are required to provide the necessary facilities, particularly as regards the instantaneous provision of alternative routes to prevent delay when cable interruptions or unexpected wireless fades occur. Details of some of the more important traffic routes will therefore be given, together with maps (see Appendix 2), on which for clarity the Empire and Empire-foreign routes are shown separately. Fig. 41 (Appendix 2) shows the main inter-Empire cable and wireless routes.

It will be observed that almost all the Empire routes from the United Kingdom are served both by cable and by wireless. London stands out clearly as the focal point of the whole system. During certain periods of the day much of the traffic between distant parts of the Empire passes through London; for example, South Africa–India traffic may travel via the Cape Town–London beam and the London–Bombay beam or via the cable chains over the same route.

The following are typical alternative routes to Australia:—

(i) By beam, either long or short route to Sydney and Melbourne, or relaying by Canada on Montreal beam.

(ii) Via Cape beam or cable and the cable chain Durban, Rodriguez, Cocos, Perth, Adelaide, etc.

(iii) Via the cable chain Halifax, Montreal, Vancouver, Fanning, Suva, Auckland, Sydney (or Suva, Norfolk, Southport, Sydney).

(iv) Via the cable chain Gibraltar, Malta, Alexandria, Suez, Port Sudan, Aden, Seychelles, Colombo, Penang, Singapore, Batavia, Cocos, Perth, Adelaide.

The choice as between wireless and cable is primarily dependent on the sender's instructions, but the particular route is regulated in part by the outpayments that have to be made on the various routes, and depends very much upon the time of traffic flow, which again is mainly dependent upon the business times in various parts of the world. During the night, for instance, on a route which is served both by wireless and by cable the cable circuit may carry the bulk of the traffic, since the majority of the cable chain stations may have to be kept fully manned to serve other routes.

Early homeward Australian traffic normally arrives via the Adelaide–Durban–Cape route, and the trans-Canadian route, so freeing the Singapore route for homeward Far-East traffic. The beam takes its share later. Thus the two methods of transmitting messages are utilized to the best advantage.

Fig. 42 (Appendix 2) shows the main Empire-foreign routes. A large proportion of the Empire-foreign traffic flows over portions of the routes shown on the previous map, and some of the routes are necessarily duplicated. London again stands out as the focal point.

The London–Rio de Janeiro and London–Buenos Aires cable circuits are particularly interesting from an engineering point of view. They are carried on a single cable chain as far as Ascension Island, the signal elements in this chain being collected from two automatic transmitters in London in the ratio of one signal element from the instrument transmitting to Buenos Aires to two from that transmitting to Rio. At Ascension the beats for Buenos Aires are picked out from the aggregate, automatically prolonged in length, and retransmitted; the gaps in the remaining elements are closed in and the signals sent on regularly to Rio. In the reverse direction the signals from the two cables are combined into the single Ascension–London chain and sorted out into their respective receivers in London, but the ratio in this case is 2 to 3, owing to the superior reception conditions at Ascension.

(4) THE COLLECTION, TRANSMISSION, AND DELIVERY OF MESSAGES

As London is the focal point of Empire communications, collection and delivery problems require more attention in London than at any other branch.

Traffic for transmission via London is collected by the following channels: (i) Branch offices in the main provincial cities or towns using private teleprinter lines or private telegraph line (see Fig. 43). (ii) Offices of the G.P.O. inland telegraph system and of the Irish telegraphs. (iii) London branch offices, by teleprinter, or by pneumatic tubes from those city offices which are situated close to the main offices. (iv) Direct from customers by private teleprinter line, telex service, private telephone line, public telephone, counters, or messengers.

Urgent and competitive traffic is most expeditiously handled, both in acceptance and in delivery, by means of private telephone lines.

Fig. 2 shows the increases in the numbers of messages accepted and delivered over the telephone at the London main branch during the years 1933 to 1937. The increases are shown as percentages of the 1933 figures. The average number of messages *delivered* over the telephone is about 9 per cent more than the average number *received* by this method. Messages received in the telephone room are conveyed by chutes, tubes, and belts direct to their respective forwarding circuits, where they are numbered, converted into the form of perforated tape, and transmitted.

All messages from London to points carrying an appreciable amount of traffic are given a prefix and numbered in series. For instance, a London–Alexandria message will bear the prefix AX followed by a number. The consecutive arrival of these numbers is checked by Alexandria, and any query is addressed direct to London. Thus, should a message be diverted from the normal London–Alexandria circuit for any reason, an intermediate station, such as Gibraltar, receiving this message in the form of perforated tape merely passes over the tape to a Gibraltar–Alexandria circuit without checking the number, the message arriving at Alexandria almost as quickly as on a direct circuit.

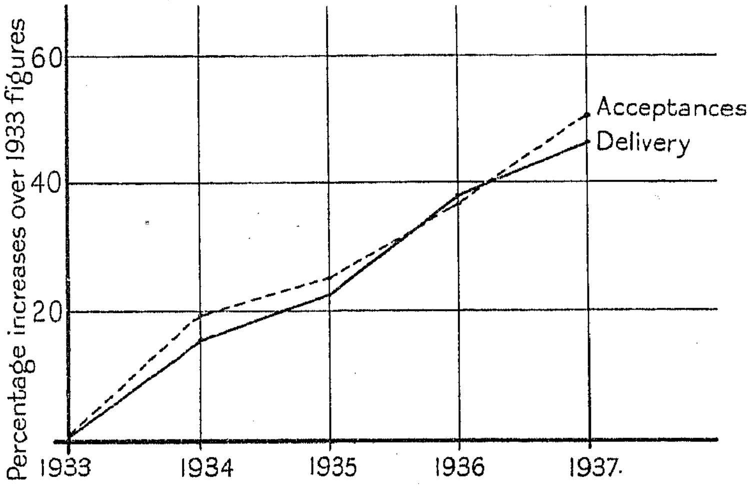

Fig. 2.—Increase in the number of messages accepted and delivered over the telephone.

Transit traffic in London is dealt with by automatic perforators. The perforators of various circuits are grouped, and the message tapes are distributed by hand into $\frac{7}{8}$-in. diameter tubes leading to the appropriate transmitting position. These tubes take the perforated tape without folding. They were first used by Mr. Christensen, of the Great Northern Telegraph Co., for the transfer of tape between the Extension and the Northern companies' offices in Shanghai.

The automatic transmitters are connected by landline or by underground cable to Porthcurno, Bodmin, Dorchester, Ongar, and Grimsby, the choice of route being decided by the traffic supervisor and the appropriate wireless transmitter by a control-room engineer in the London building.

The delivery of messages is carried out by substantially the same means as the collection of messages.

(5) SIGNALLING CODES USED IN TRANSMISSION

The three-positional "cable code" using the standard morse alphabet is in use on nearly all the cables of the service. A dot is represented by a negative impulse to line, a dash by a positive impulse to line, and a space by no current, all signals being of equal length. The cable code has two great advantages over other codes in general use: (i) The majority of instrumental errors are readily detectable. (ii) Intelligence can be transmitted over a long submarine cable more rapidly and under more stable conditions by cable code than by any other code. The devices by which signalling speed with the Morse Code or the 5-unit code can be brought to approach the maximum cable-code speed of a cable produce instability and limitations with regard to duplex balance and change of speed.

With regard to the first point, errors in transmission can practically be confined to (*a*) one or more elements lost, (*b*) one or more elements inserted. In cable code the loss of a beat at the beginning or end of a letter will result in a double space, which is easily detected. The loss of a beat other than the first or last in a letter will result in the breaking-up of one letter into two, producing in a 5-letter code word, a 6-letter word, detectable as a miscount. The insertion of a beat in the space between letters will run two together, either making an unprintable combination or producing a 4-letter code word.

In 5-unit code the insertion or dropping of a beat generally results in the substitution of one letter for another, a fault usually quite undetectable in a code word.

With regard to the second point, with morse signalling on a long submarine cable it is necessary, in order to convey the same amount of intelligence in a given time, to increase the number of bauds transmitted by 152 per cent, i.e. by 3·6 to 9·0 bauds per letter. This can be attained only by attenuating the dots until they are not appreciated by the primary receiving instrument, and by re-inserting them locally. A three-positional relay is required, since the morse signals in effect arrive as a three-positional code, i.e. space-zero-mark.

The zero element, being the result of a balance between mark and space at the far end, is susceptible to bias, and on a reduction of speed the indication of transmitted dots is no longer zero but an attenuated reversal. Thus, with receiving conditions at their optimum value for the best speed on a long cable, a reduction of speed results in loss of stability until a point is reached where the attenuated reversal is too large to allow the relay to remain in an inoperative position but is yet too attenuated to operate the relay correctly. Fig. 3(*b*) is a graph of the movements of the relay pointer under this critical condition. The dotted horizontal lines show the points at which the relay will operate its local circuit; it will be noted that any displacement of zero or any balance disturbance will cause interference with the robust control of the local circuits of the relay.

Inability to reduce speed without change of receiving conditions is a grave disadvantage, since it prevents the easy interpolation of a fast cable in a comparatively slow-working chain. Again, a reduction of speed which may be desirable for balance or other purposes produces instability instead of improving a circuit. Cable code does not suffer from this defect, since the zero unit remains zero at all speeds.

The use of morse double-current signalling at the sending end introduces difficulties in the duplex balance owing to the quick reversal, and greater perfection of balance is necessary owing to the greater number of frequencies introduced.

Five-unit code suffers from the same disabilities. Although the increase of bauds necessary to equal the performance of cable code is not so great as with morse, the fact that the local vibrating relay must be held up by a mark or space of 2 bauds' length instead of 3, as in morse, prevents full advantage being taken of the smaller number of bauds required per letter.

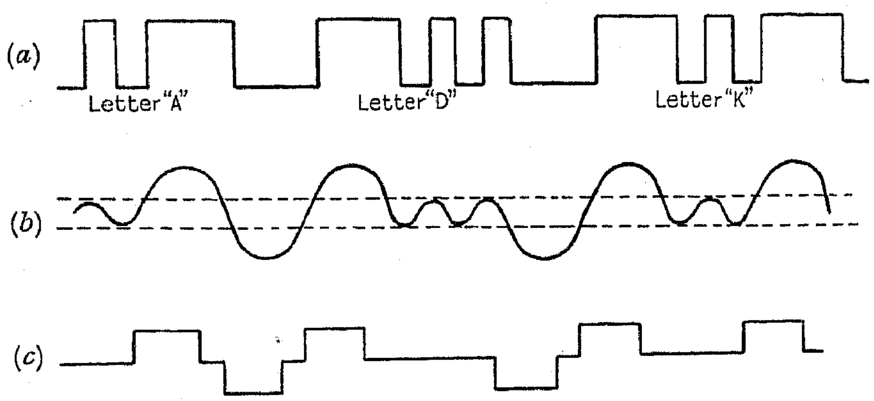

Fig. 3.—Double-current morse on cables.

(*a*) Transmitted morse signals.
(*b*) Received signals (dotted lines show "no-man's-land" of receiving relay).
(*c*) Output of receiving relay which controls vibratory system.

A two-positional code having some of the advantages of the cable code, and known as the "double-current cable code," has been brought into use on landline circuits and wireless circuits where regenerator systems are worked. In its simplest form, as used on landline circuits and on some wireless circuits, the dot consists of a marking impulse and the dash of a spacing impulse, but the zero interval for a space signal is replaced by a 50 % mark signal, followed by a 50 % space signal. This code[*] has been described briefly in a previous paper,[†] but a further explanation is added here to clarify later developments.

Fig. 4 compares the double-current cable code with the normal cable code. It will be observed that when the double-current cable code is in use it is necessary to separate the dot and dash selection points of the regenerator apparatus, a dot being selected three-quarters of the way along the unit signal period and a dash one-quarter of the way along. The double-current cable code has the advantage that a dash occupies only 2 bauds, thus increasing the traffic-carrying capacity of a voice-frequency channel or a limited wireless circuit by over 30 % as compared with the Morse Code.

A further elaboration of this code (see Section 7) has been made for use on those beam wireless circuits which are worked on a channelled regenerator system.

(6) PROGRESS AND PRESENT METHODS IN CABLE TELEGRAPHY

General

No important long cables have been laid in recent years, as the service has been able to cope easily with existing traffic.

It is sometimes asserted that improvements in cable systems were not made until wireless competition was experienced. Substantial progress was, however, made before as well as after the advent of wireless. As early as 1900, relay reception with automatic re-perforation was accomplished, while in 1912 mis-selection due to distortion was minimized by mechanical delay of the selecting point to the centre of each beat—a principle which is incorporated in present-day "regenerator" systems. By 1914 a number of cables were equipped with regenerator apparatus and a beginning had been made in linking sections together, thus laying the foundations of the present world-wide chain systems.

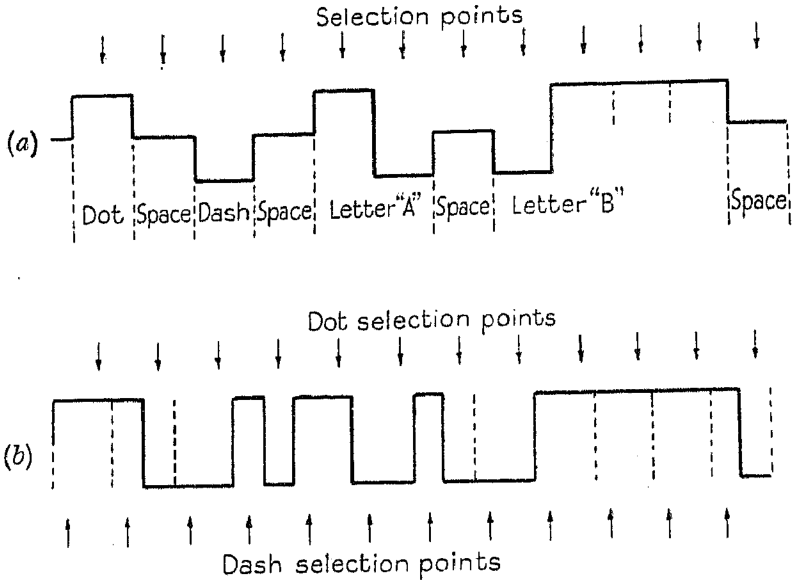

Fig. 4

(*a*) Normal cable code.
(*b*) Double-current cable code: same signals as in (*a*).

The abnormal demand upon communications personnel during the War precluded any experimental work from 1914 to 1918. At the same time the expansion of traffic and the availability of morse re-perforators led to a change-over from cable code to morse. Defects in this system were experienced and, when research again became possible, work was continued with cable code on a system employing continuously synchronous apparatus instead of the start-stop synchronism of the 1912 apparatus. By 1923 the "regenerator" had been perfected, and during the next 4 years the appropriate instruments were manufactured and supplied to 120 stations, effecting an immediate improvement in reliability and a speed-up of the service.

The principles of synchronous regenerator working are well known and have been fully described in the *Journal*.* Special problems, however, arose in the Empire service. The number of cables which had to be linked up to form single regenerator chains was so much larger than on any other cable system that it was necessary to develop more precise methods of speed control and synchronization.

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[*] H. V. Higgitt: British Patents Nos. 267180 and 294715.

[†] H. Kingsbury and R. A. Goodman: "Methods and Equipment in Cable Telegraphy," *Journal I.E.E.*, 1932, vol. 70, p. 477.

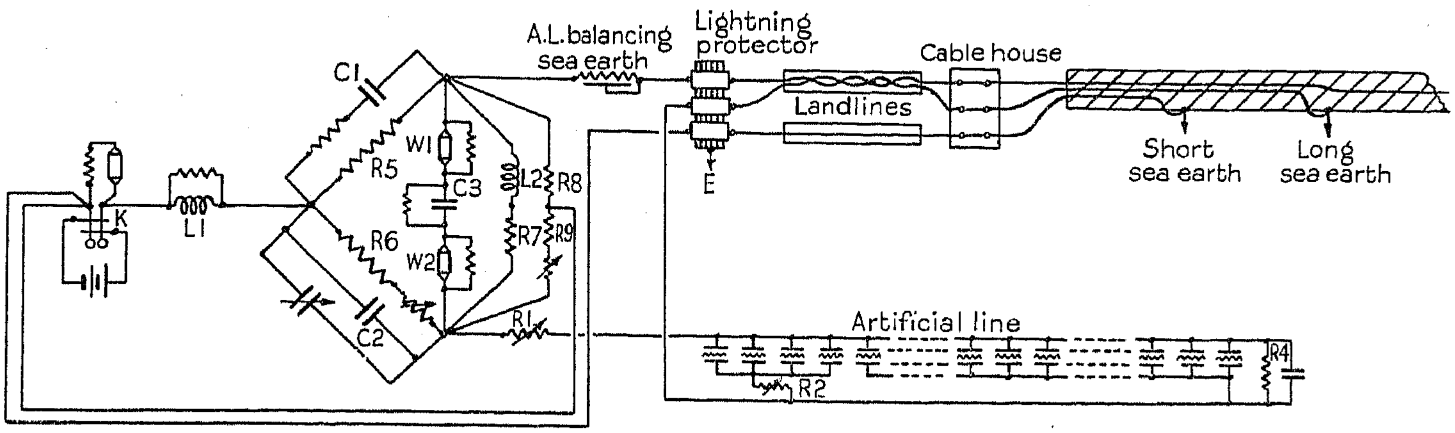

Fig. 5.—Complete duplex network on submarine cable.

Since that date various devices have been incorporated in regenerator equipment which have had the effect of increasing working speeds and further improving the reliability of the system.

Figs. 5 and 6 show respectively the complete duplex network and the component parts of the regenerator system as at present operated. Means of measuring signal distortion are incorporated in the regenerator apparatus. While the regenerator itself is capable of transmitting practically perfect signals from badly distorted received signals, it was soon realized that the undue distortion of certain signals limited the speed. This drawback led to a close investigation into the networks used, with the object of finding the best arrangement and the optimum values of the sending and receiving "shaping" conditions.

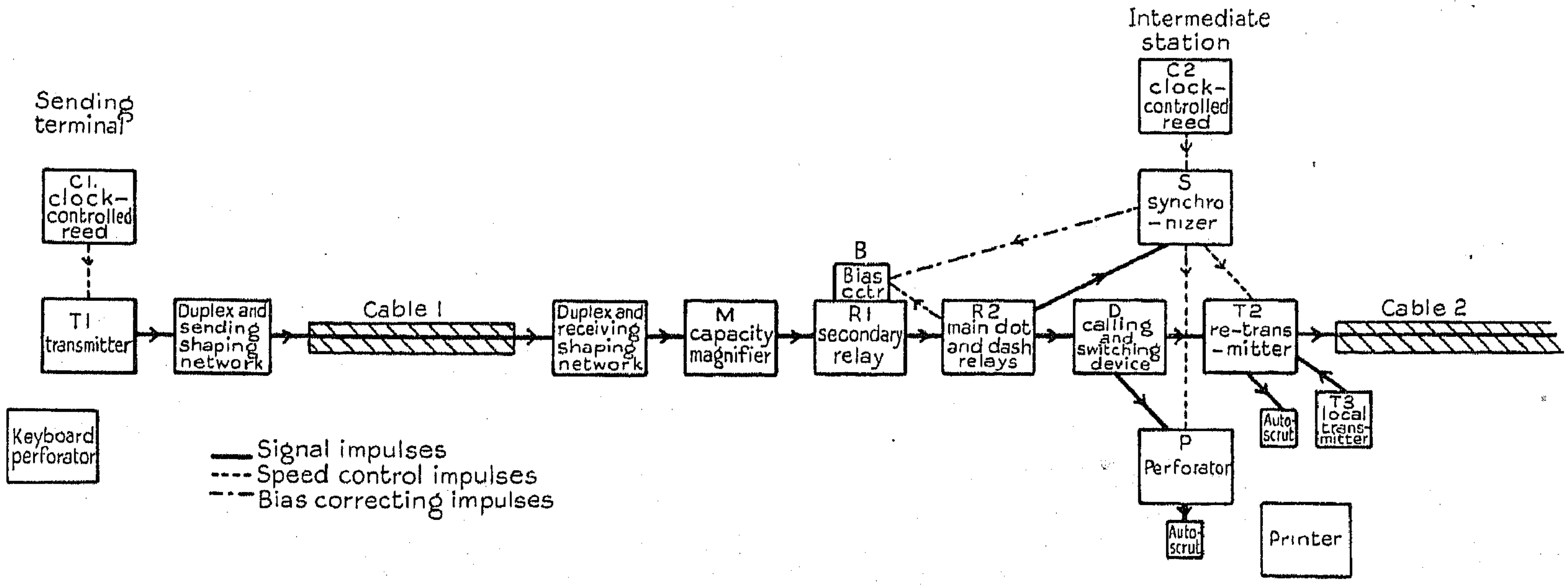

Fig. 6.—Component parts of regenerator system.

From Fig. 5 it will be seen that the system is based on the original Muirhead capacitance bridge. The ratio arms C1 and C2 of the bridge are shunted by resistors R5 and R6 with values of some thousands of ohms. The cross circuit is composed of the two windings, W1 and W2, of the receiving instrument (described later), with the shunted capacitor C3 of the receiving-circuit network inserted between the two windings in order to achieve symmetry in relation to earth. Across this combination is the inductor L2, with series resistor R7, in parallel with a second system of bridge arms, R8 and R9, having an adjustable point connected to earth. These arms form what is known as an "extra apex."

Between the transmitting key or transmitter K and the normal apex of the bridge is an inductor L1. The function of this inductor is to raise the effective voltage at the head of the cable during the signalling of the higher frequencies and also to change the wave-form of the potential applied to the cable and artificial line from a sharp rise to one approximating to a sine wave, thus substantially reducing quick and violent currents caused in the cross circuit by small errors in the duplex balance. Fig. 7 (see Plate 1, facing page 644) shows the wave-forms of the voltage at the head of the Porthcurno-Gibraltar No. 3 cable, for signalling (i) with and (ii) without the inductor L1. The peak at the beginning of each signal in Fig. 7(*b*) which introduces balancing difficulties, is absent in Fig. 7(*a*), and the potential over the main portion of the signal is increased. Formulae are available for calculating the best value of inductance at the apex and the resultant increase in potential at the head of the cable, but so many factors, such as the lack of homogeneity of the cable, have to be taken into account that these formulae give starting values only; the best values, as found by practical trial, usually differ widely from the calculated values.

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* H. H. Harrison: "Developments of Machine Telegraph Systems and Methods of Operation," *Journal I.E.E.*, 1930, vol. 68, p. 1369.

The effect of L1 on the received signals on the same cable is shown in Fig. 8 (Plate 1). The increase in the size of the signals of high frequency is very marked, amounting in this case to over 20 % of the signal.

Unshunted capacitance bridge arms practically prevent the passage of earth currents into the cross circuit. On the other hand, when a succession of beats of the same polarity is sent by the distant end, the received current falls away, and the receiving relay is not maintained in a marking position. S. G. Brown devised a method of correction in which a local current flowing in an auxiliary winding of the receiving relay increased at the same rate as the fall-away; this arrangement necessitated a delicate balance of forces, and proved troublesome in practice. The shunting of the capacitors by resistors of high value provides the necessary hold-up current from the distant end, but it permits the entry of earth currents. Effective means have, however, been devised in the regenerator system for dealing with the zero-wander resulting from these currents.

The addition of the shunts had the further effect of giving rise to a slow wave during signalling, owing to the charging-up of the terminal and artificial-line capacitance at the receiving station by the received current; this wave was reduced to a negligible amount by the addition of the " extra apex " resistance arms R8 and R9 at both ends of the cable, as shown in Fig. 5.

Fig. 9 (Plate 1) illustrates the effect on the received signals in the Porthcurno–Gibraltar No. 3 cable of removing the extra apex at each end. The normal signals are as in Figs. 9(*a*) and 9(*g*); Fig. 9(*b*) shows the signals received after the extra apices had been removed, and Fig. 9(*c*) the signals after compensation had been made elsewhere in the networks to regain the best shape of signal. The slow wave referred to shows up to the greatest extent in these last signals when a series of beats of the same sign are being sent. Sections of the signals from Fig. 9(*c*) have been enlarged to show this point more clearly, and a straight line has been added on the tapes for the same reason. Figs. 9(*d*) and 9(*e*), Plate 2, show the beginning and end of the series of signals of the same sign. The quick dip at the beginning of the series, which shows up again in Fig. 9(*f*), can be eliminated without the introduction of extra apices, but its elimination results in even greater wandering of the remainder of the steady signals, and a consequent general wandering of the signal zero. If extra apices are not used it is therefore necessary to effect a compromise.

The shunted capacitor in series and the inductor in parallel with the relay windings are adjusted so that the increase in impedance in series with the coil and the decrease in parallel are such that, although the current from the cable due to a succession of beats of the same polarity is increasing in value as the cable becomes charged, the current through the windings remains constant.

Referring to Fig. 6, the clock-controlled reed C1 controls the speed of the automatic transmitter T1. This transmitter, for the purpose of easy interchange of traffic between wireless and cable circuits, is made capable of sending cable-code signals from either Wheatstone or cable-code slip at will. The transmitter sends into the cable through the duplex terminal apparatus, as shown in Fig. 5, and after passing through similar equipment at the distant end the shaped received signals are amplified by the magnifier M and are passed on to the contact-making secondary relay R1. The contacts of this relay operate more robust relays R2. These relays assist in the operation of the bias corrector B, attached to the secondary relay R1, and also operate the selector magnets either of a re-transmitter T2, or of a perforator P, or of both, according to the position of a switching device D. The re-transmitter T2, kept in synchronism by the synchronizer S, re-forms the distorted signals operating its selector magnets, and, by means of cam-operated contacts, sends on signals with practically perfect formation into the next cable.

The perforator P, also running synchronously, starts perforating as soon as its selector magnets are brought under the control of the main relays by the insertion, at the transmitting end, of a special combination of signals which operates the switching device.

The relays R2 also operate a relay in the synchronizer S; this relay, when operated, discharges a capacitor in one or other of two paths according to the phase position of a contact device driven by a motor under the control of the clock-controlled reed C2. The relative speeds of the two clock-controlled reeds C1 and C2 are thus compared, an excess of impulses in one path indicating a difference in speed. Means are provided in the synchronizer for utilizing these impulses to make appropriate alterations in the speed of the motors of T2 and P so that their operative parts act substantially in the centre of each received signal.

While a message is being automatically received on the perforator at an intermediate station of a chain of regenerative repeaters, or during pauses in the terminal transmission, it is possible for the intermediate station to forward a message without interfering with the synchronism of the chain. A switch that can be turned by hand connects a small automatic transmitter T3, incorporated in the re-transmitter, to the selector magnets of the re-transmitter, thus initiating signals in the next cable. Should the terminal resume transmission before the local message is finished, the switch is automatically returned to the through working position and the feed of the perforated tape of the local message is stopped.

At the terminal of a chain of cables the re-transmitter is omitted and the whole of the traffic is received on the receiving perforator P (Fig. 6); the perforated tape from this is fed into a Creed printer, so producing roman characters. This method is now giving way to a new printer which translates the cable-code signals directly into roman characters without interposing the perforated slip.

An automatic scrutinizing device is fitted to both perforator and re-transmitter. This device gives warning when the signals have deteriorated to such an extent that danger of failure is approached, the normal causes of deterioration being changes in the duplex balance,

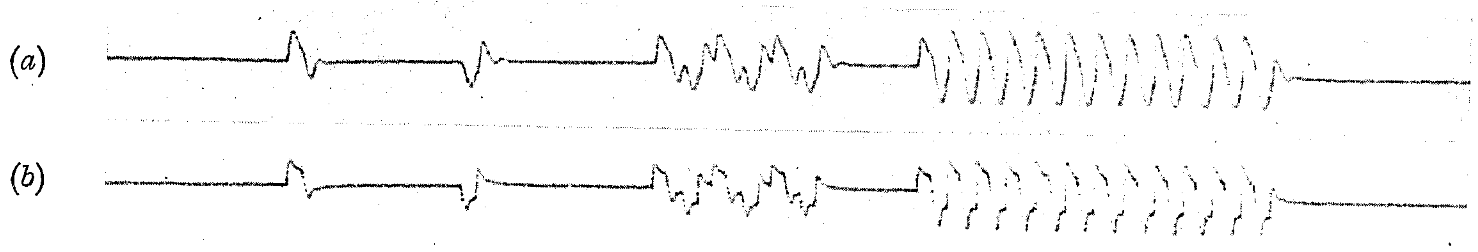

Fig. 7.—Wave-form of transmitted signals, (*a*) with apex inductor L1, (*b*) without apex inductor L1.

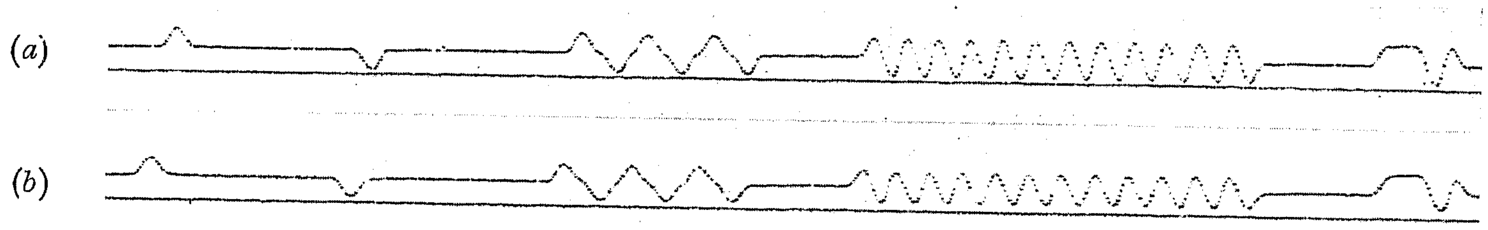

Fig. 8.—Wave-form of received signals, (*a*) with apex inductor L1, (*b*) without apex inductor L1.

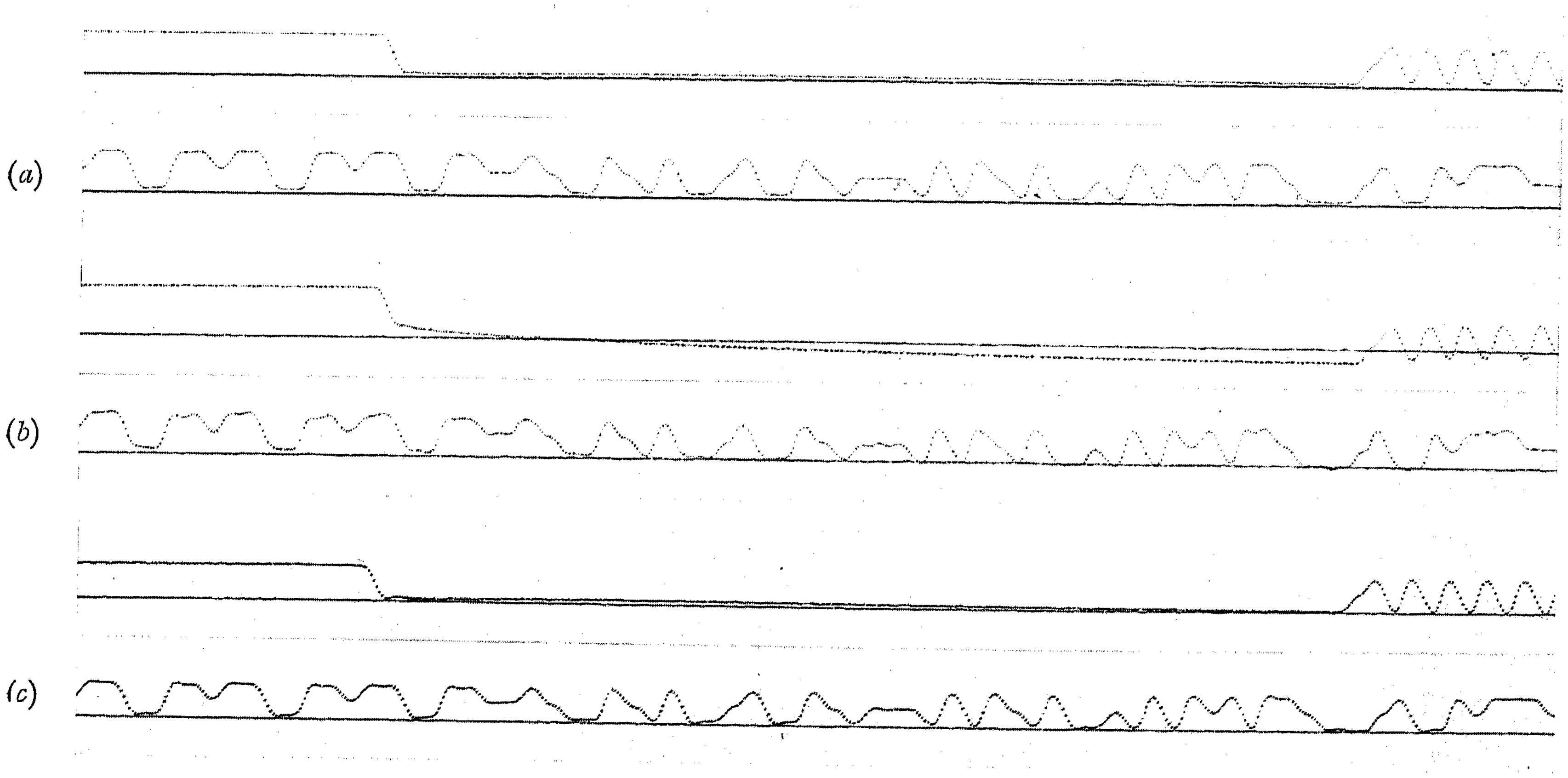

Fig. 9.—Received signals with and without extra apices in sending and receiving networks.

(*a*) Normal signals.
(*b*) Extra apices removed at both ends.
(*c*) Compensation made elsewhere in networks to regain best shape of signals.

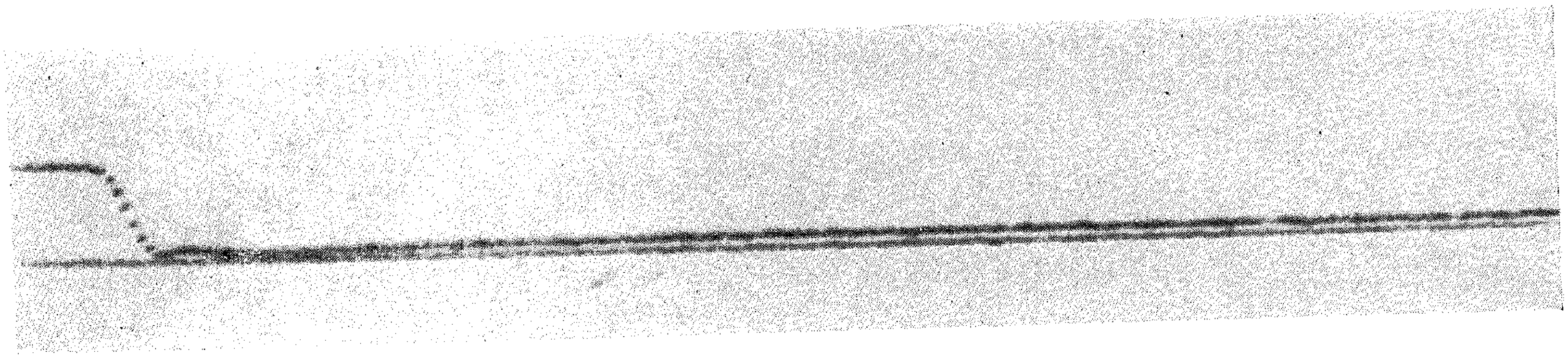

Fig. 9(*d*).—Enlargement of beginning of steady signal in Fig. 9(*c*).

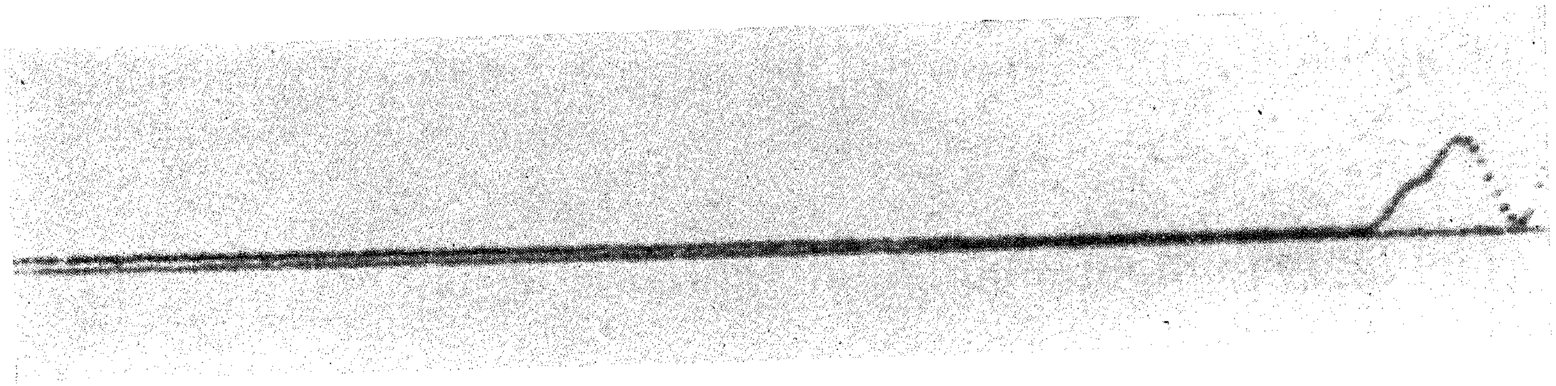

Fig. 9(*e*).—Enlargement of end of steady signal in Fig. 9(*c*).

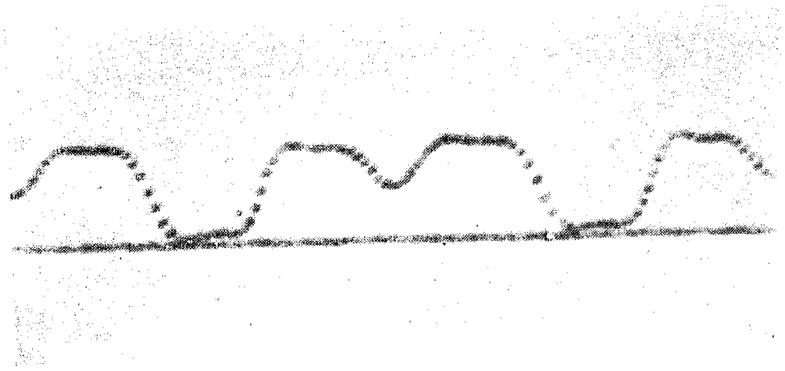

Fig. 9(*f*).—Enlargement of signals from Fig. 9(*c*).

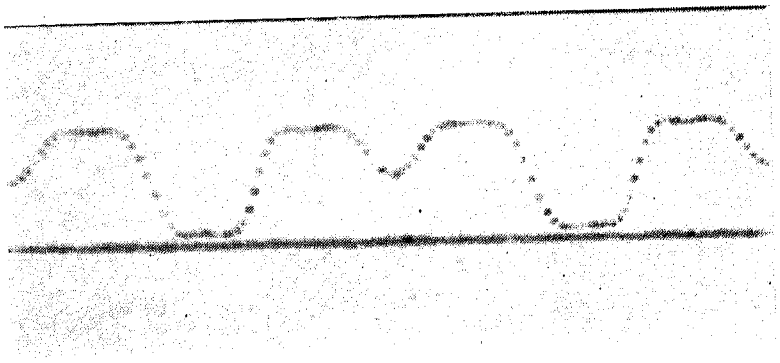

Fig. 9(*g*).—Enlargement of signals from Fig. 9(*a*).

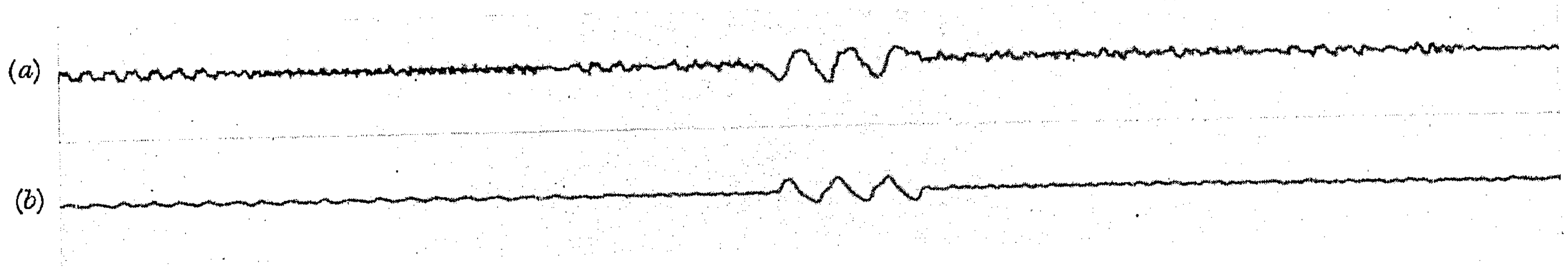

Fig. 11.—Filtering effect of magnifier coil.

(*a*) Input of magnifier amplified to normal signal size by valve amplifier.
(*b*) Output of magnifier from same input.

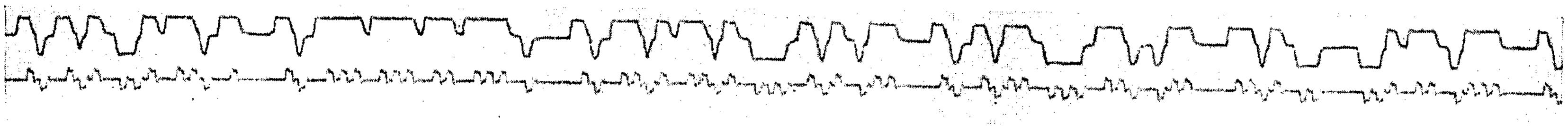

Fig. 17.—Secondary-relay signals, showing rapid removal of heavy bias.

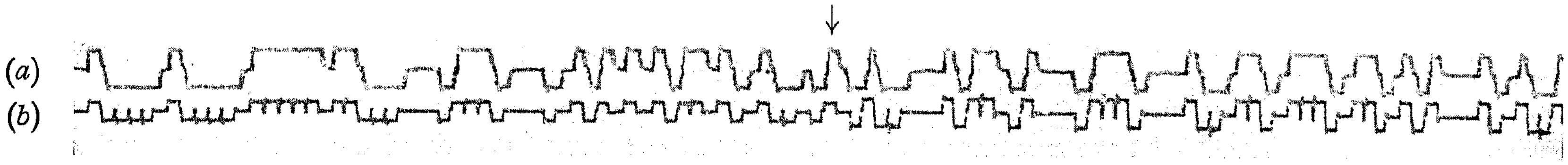

Fig. 19.—Action of automatic scrutinizer.

(*a*) Received signals.
(*b*) Retransmitted signals.

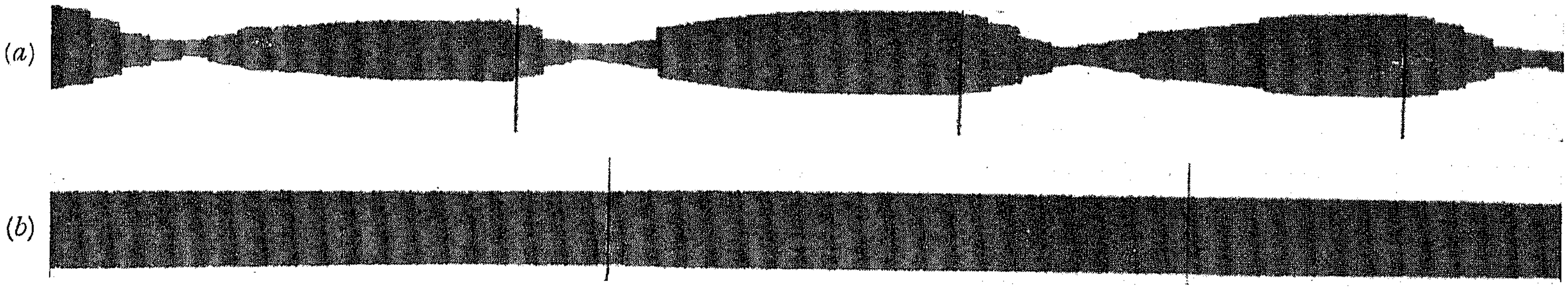

Fig. 20.—Comparisons of the frequencies of two reeds when the voltage applied to one is varied.

(*a*) With normal adjustments.
(*b*) With new method of adjustment.

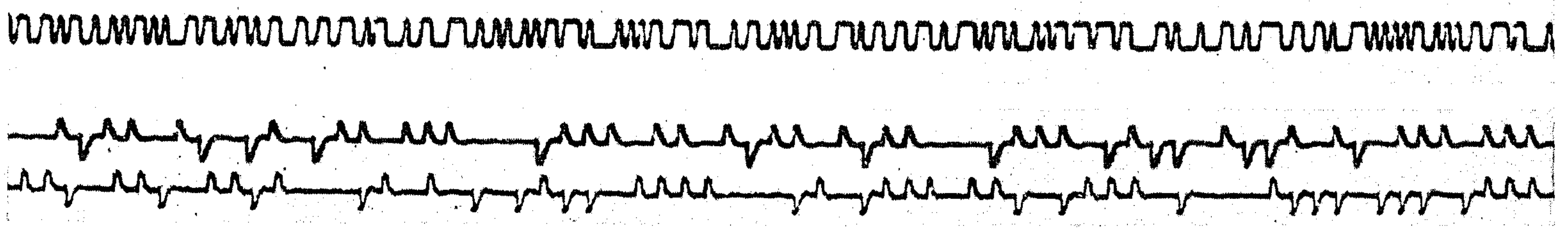

Fig. 22.—Records of double-current cable code signals on Bombay–London beam.

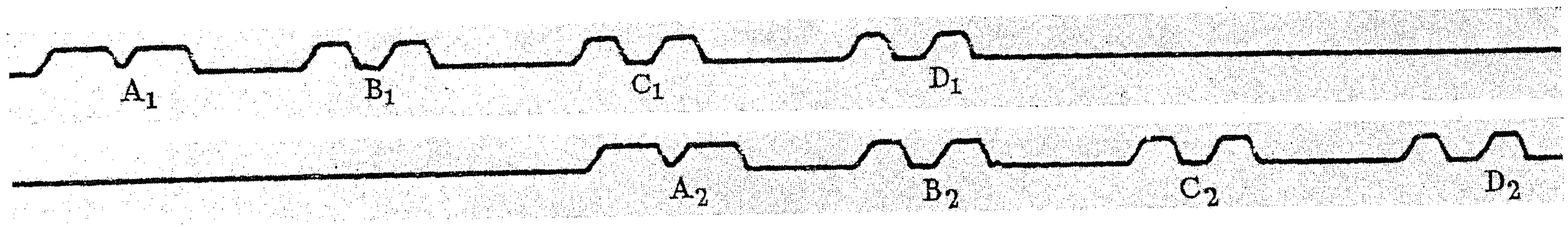

Fig. 35.—Multiple echoes.

This is a continuous record, the tape being cut for ease of reproduction.

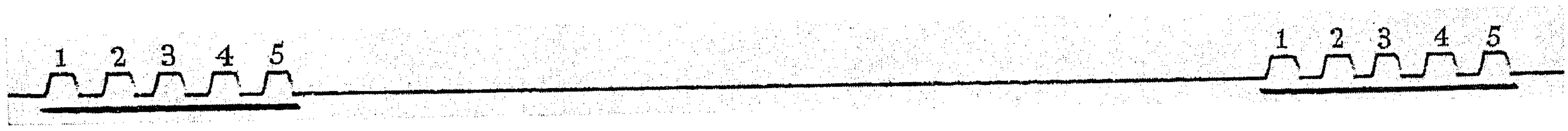

Fig. 36(*a*).—Forward and backward echoes.

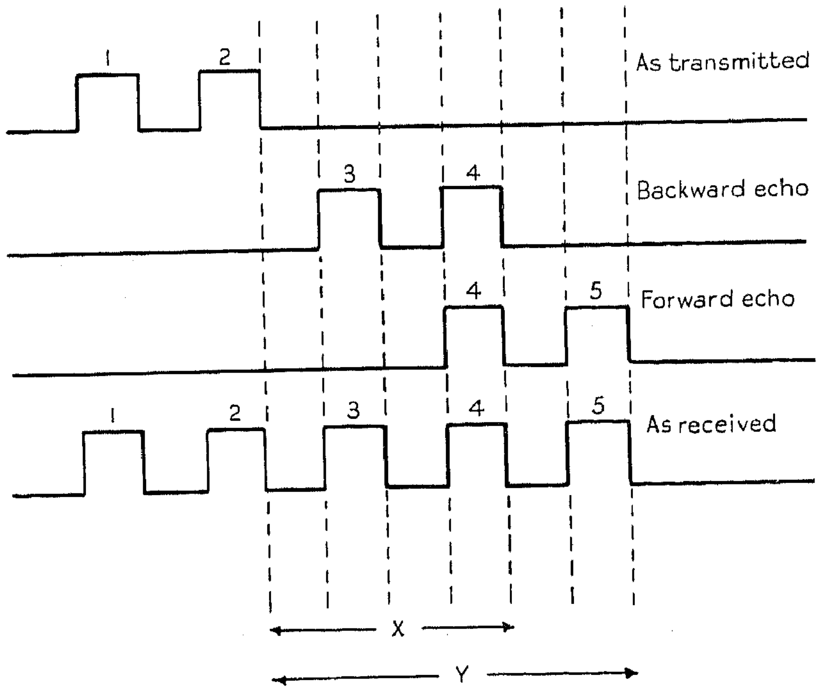

Fig. 36(*b*).—Forward and backward echoes.

excessive bias, speed sway, and poor contact. The warning usually takes the form of the lighting of a lamp and the augmentation of the signals on a local record at the point where the device functioned. In particular cases, however, a single-stroke bell may be rung, and on circuits where no permanent record is running the device may be used to start up a local record. The attention of the watch engineer is thus drawn to some deficiency in his apparatus before errors actually occur, and in this way stoppages are avoided which, in some cases, would necessitate the attention of as many as 16 other engineers distributed at stations on a chain of cables. In addition, therefore, to the substantial reduction of stoppages and the prevention of many errors, this device has enabled staff economies to be effected.

Although the modern apparatus may appear to be delicate and complicated, in actual practice it is normal to run as many as 17 sets—2 terminal and 15 intermediate stations all working in synchronism—on a chain of cables reliably and without undue attention.

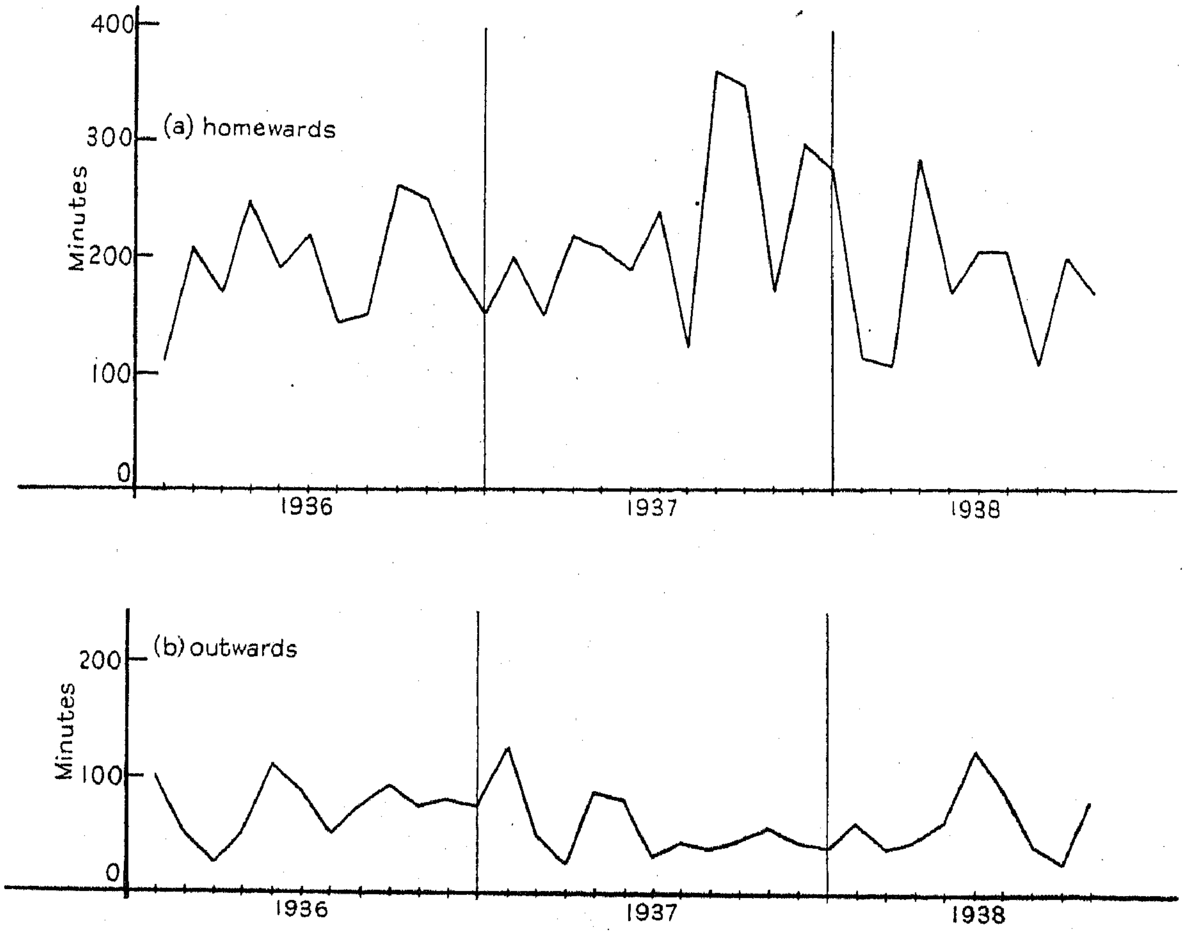

Fig. 10.—Graphs of stoppages at main-line station having 20 duplex circuits.

Fig. 10 shows a typical stoppage graph at a branch with 20 duplex circuits equipped as described, the graph covering the period from January, 1936, to September, 1938, inclusive. The abscissae represent in minutes per month the total stoppages on all circuits due to this particular branch. Stoppages caused by cable interruptions are not included. At this branch, submarine cables are connected to landlines, so that the difference between the upper and lower graphs represents stoppages due to difficulties in maintaining the duplex balance on the cable sections. The average stoppages work out at 0·69 minute per circuit per day of 24 hours in one direction and 0·23 in the other.

Details of Apparatus

The clock-controlled reed* and automatic transmitter† are fully described elsewhere.

The capacitance magnifier.

As the speed of transmission of signals through a cable is increased, a point is reached where attenuation becomes so great that reliable operation of contact-making relays is no longer possible. Some means of amplifying the signals before passing them to the relay is therefore necessary if an increase in speed is to be achieved.

It might be thought that valve amplification would provide the best solution of this problem, but the merits of the moving coil as a simple and efficient filter of the unwanted higher frequencies present in the duplex balance outweigh all other considerations.

Fig. 11 (see Plate 2) shows a comparison between a bad duplex balance outness as applied to the input of a moving-coil magnifier and the outness as applied to the secondary relay after the filtering effect of the magnifier coil. The large reversals represent the size of normal signals. In each case the records were obtained through a valve amplifier, the gain being adjusted to give approximately equal sizes of signal.

The capacitance magnifier‡ (Fig. 12), however, combines the use of valves with the moving-coil principle. A light aluminium pallet P, carried on an aluminium arm AA, is attached to, or in some cases harnessed to, the main coil of the magnifier. The vanes of the pallet are adjacent to two fixed sets of plates E, termed the fixed electrodes, a movement of the magnifier coil MC increasing the capacitance between the pallet and one set and decreasing the capacitance between the pallet and the other set. The two sets of fixed electrodes are connected to the grids of two rectifying valves V1 and V2 by short lengths of wire. Oscillations from a self-oscillatory valve circuit V3 are tapped off on a capacitor potentiometer and applied to the pallet. The rectifying valves, together with two resistors of approximately 1 000 ohms each, form a bridge circuit across which is connected the coil of the secondary instrument.

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* H. H. Harrison: *Journal I.E.E.*, 1930, vol. 68, p. 1377.
† British Patent No. 26278—1913.
‡ British Patent No. 277740.

A movement of the pallet increases the mean potential applied to one grid and decreases that applied to the other grid, causing variations of the plate currents in the valves and a consequent flow of current in the coils of the secondary instrument FC.

The rectified current in the cross circuit is substantially proportional to the movement of the pallet, up to a limit of 1 mA of rectified current with the degree of magnification that is normally used. This means that a considerable wandering of the magnifier pallet due to earth currents may take place without appreciably distorting the output signals—apart, of course, from zero-shift.

The capacitance magnifier will operate on a current of 2 microamperes, corresponding to an input voltage of 1 millivolt. Normal received currents on a cable after passing through the shaping networks are greater than this, being of the order of 10 microamperes for a long cable and more for shorter ones, giving, with a magnification factor of 7 or 8 to 1, ample current to work the secondary relay. In special cases an amplification of 90 to 1 has been obtained from this instrument.

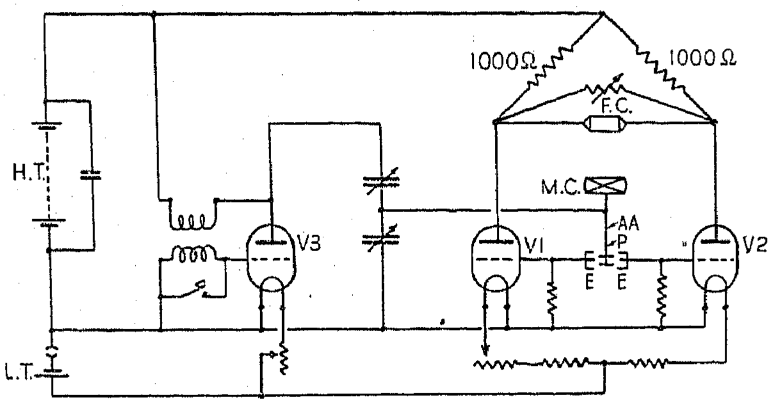

Fig. 12.—Capacitance magnifier.

Secondary relay.

This relay, known as the "fork relay," is of the moving-coil type but it has the unique feature that the contact elements make contact when at rest. The movement of the relay coil in one direction beyond a predetermined amount breaks contact on one side and maintains contact on the other, thus upsetting the balance of a bridge circuit and operating one local relay. Movement in the other direction causes an opposite upset, so operating the other local relay.

The tongue of the fork relay, attached to the wire-suspended coil, consists of two short gold-wire antennae arranged like a 2-pronged horizontal fork, the antennae being adjustably compressed between two silver pillars which are kept in a state of vertical vibration. The amount of compression determines the angle through which the coil has to move before one wire breaks contact, and is therefore comparable to the transit of the tongue of an ordinary relay. Reliable contact-breaking can be carried out with a current of 60 microamperes through the 500-turn 500-ohm coil. The movement of the coil can be read for balance and signal-shape purposes by light reflected from a mirror harnessed to the coil.

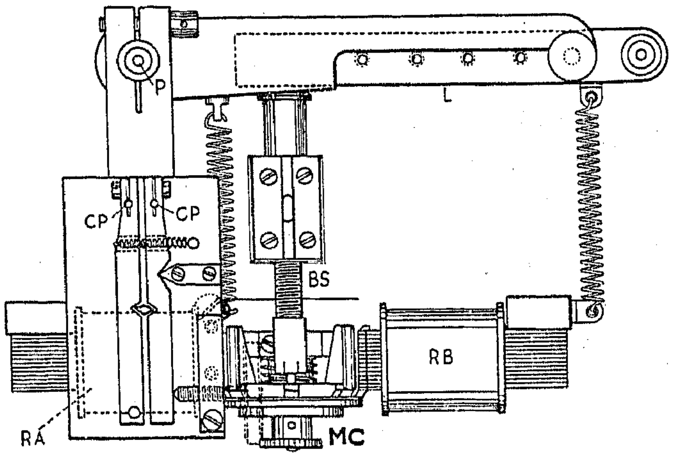

Fig. 13A

Bias corrector.*

As already mentioned, the shunts on the capacitance bridge permit earth currents to reach the receiving network, and the necessary bias correction is most conveniently carried out on the secondary relay.

A plan view of the bias-adjustment mechanism attached to the fork relay is shown in Fig. 13A, and an elevation of the magnetic-clutch mechanism in Fig. 13B. The silver contact pillars CP are carried on a platform attached to a shaft which is V-pivoted at a point P below and on the same axis as the moving coil; this shaft can be turned by a bias screw BS through a lever system L, in which there is no backlash, so as to bring the pillars into such a position that equal movements of the coil can be made on each side before a contact is broken. The bias screw can be turned by means of a small magnetic clutch MC (Fig. 13A) which operates in one direction or the other according to which magnet is impulsed.

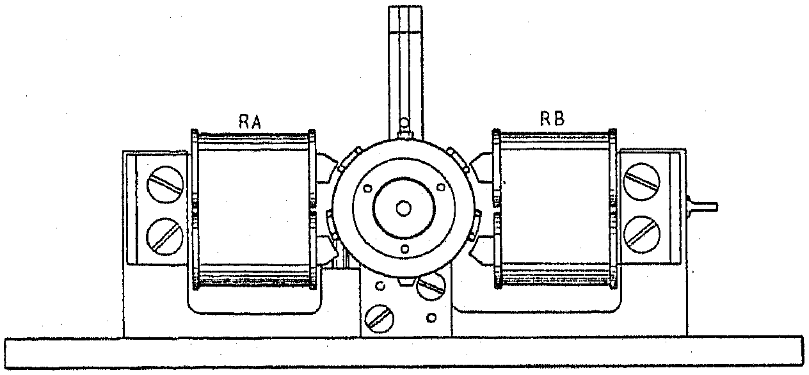

Fig. 13B.—Bias corrector attached to secondary relay.

The schematic connections of the bias-corrector system are shown in Fig. 14. The magnets RA and RB, which operate the clutch, are differentially wound, the windings being connected to the dot-and-dash relays operated by the secondary relay, and to a pair of relays RE and RI which are operated by the advance and retard of the synchronizer.

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* British Patent No. 240906.

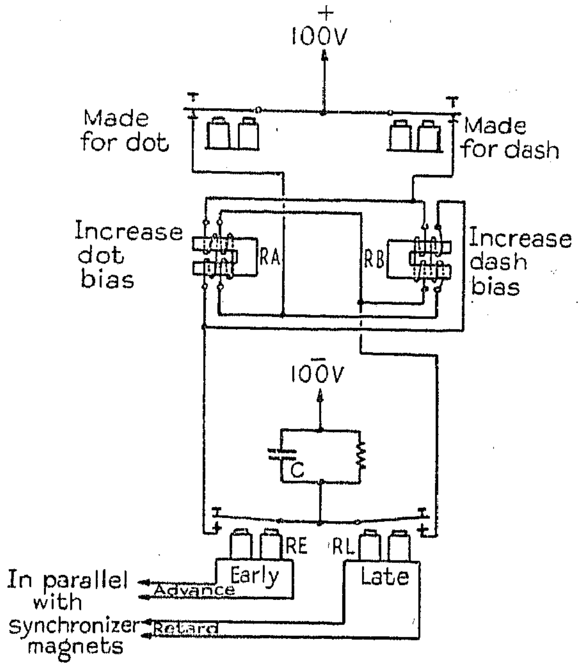

Fig. 14.—Diagram of connections of bias corrector.

Fig. 15(*a*) is a graphical representation of the movements of the relay antennae, the movement being plotted vertically against regular time-intervals shown horizontally, corresponding to the times of arrival of perfect signals. A dash bias resulting from a steady earth current is assumed to exist. The horizontal dotted lines denote the position at which the relay operates its local circuit, the resultant contacts of the main dot and dash relays being shown in Fig. 15(*b*). When the local circuit is operated a capacitor discharge energizes the synchronizing magnets of the synchronizer momentarily to alter the speed of T2 and P (Fig. 6); at the same time the discharge operates the magnets RE or RL (Fig. 14) of the bias corrector. Under dash bias conditions, as shown, it is arranged that the current from the capacitor C (Fig. 14), resulting from the operation of RL and the dot relay, flows in such a direction in the windings of RA and RB that the two windings of RA assist each other, and those of RB oppose each other. This causes the magnetic clutch to operate the bias screw in such a direction as to remove the dash bias. An early dash signal has a similar effect. If a dot bias exists, so causing early dots and late dashes, RB will be operated, moving the bias screw in the opposite direction. If, when the bias is correct, both dots and dashes are early or late owing to speed-difference, the false step taken in one direction by, say, an early dot, is in practice countered by a step in the other direction resulting from an early dash.

The amount of correction applied per impulse can be varied in the lever system and by adjustment of the capacitor C; it is adjusted so that in all but the worst magnetic storms the movements of the relay coil can be followed without producing sufficient distortion to cause trouble.

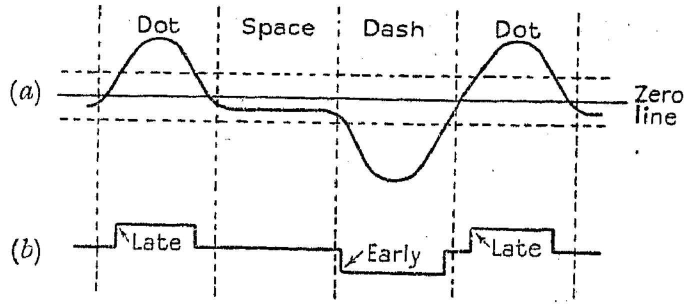

Fig. 15

(*a*) Received signals with bias resulting from earth current.
(*b*) Resultant main dot and dash relay contacts.

Fig. 16 shows typical variations of earth currents during a period of 3 days on the Harbour Grace–Porthcurno cable under normal conditions. The earth-current amplitude is compared with the signal amplitude. Fig. 17 (Plate 3) shows signals obtained from the fork relay when an additional potential of 18 volts was suddenly introduced into a long cable working with a 60-volt sending battery. With normal adjustments of the bias corrector the bias was removed in 12 seconds. It will be realized that the normal earth current changes reasonably slowly, and that an instantaneous change of as much as 18 volts corresponds to severe magnetic-storm conditions. In practice, the fork relay with bias corrector has functioned satisfactorily with earth currents causing bias outnesses up to 3 or 4 times the signal amplitude at the receiving end.

Calling and switching device.

For complete flexibility on a long regenerator chain it is necessary that the terminal transmitting station should have complete control of the chain and should be able to call the attention of any individual intermediate station at any time. With these objects, a selective calling and switching device is provided at intermediate stations. Two magnets, operated directly from the dot and dash relays, control two camshafts by means of pawls and ratchet wheels.

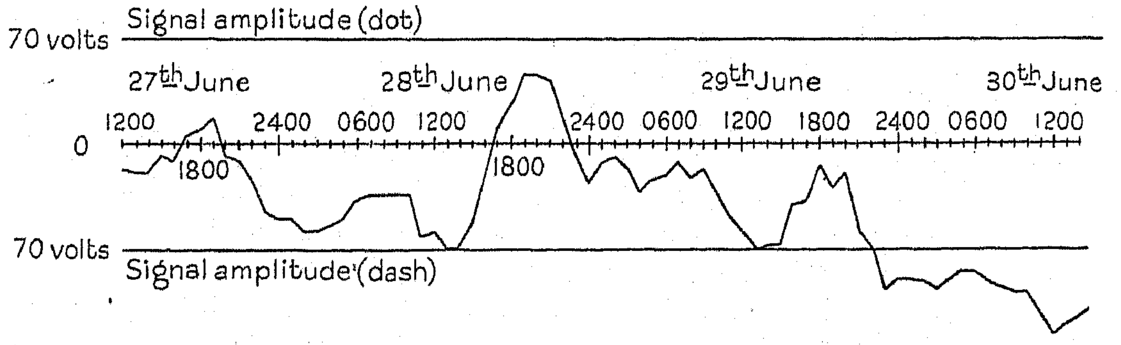

Fig. 16.—Earth-current variation on Harbour Grace–Porthcurno cable during a period of 72 hours: hourly observations at Porthcurno.

A dot signal feeds the dot camshaft forward one tooth of the ratchet wheel, in which position it is held by a detent; at the same time the detent of the dash ratchet wheel is lifted, allowing the dash camshaft to return to zero. In a similar manner a dash signal feeds the dash camshaft forward one tooth and resets the dot camshaft to zero. Thus normal traffic continually resets the camshafts, and does not allow a prolonged feed on one side.

In order that the device may be made selective, cams on the dot and dash camshafts periodically operate contacts which short-circuit the dash and the dot feed-magnets respectively. By fitting different short-circuiting cams to each call device on a chain, each station may be made to respond to a different call. By building up the appropriate number of impulses either camshaft can be used for any desired switching function, such as calling attention on through circuits which are not staffed, the temporary switching-in of re-perforators, or the directing of traffic over selected routes.

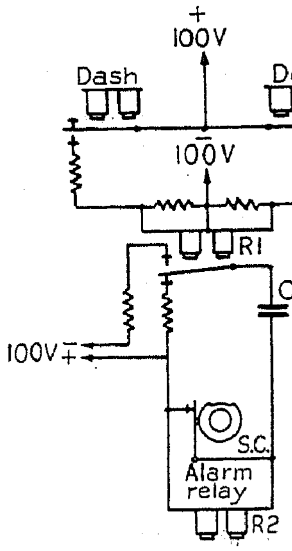

Fig. 18.—Diagram of connections of automatic scrutinizer.

The delay due to switching signals is very slight, the line time occupied by call being of the order of only 4 seconds on a circuit working as slowly as 1 000 signal elements per minute.

Automatic scrutinizer.

A schematic diagram of the connections of this device is shown in Fig. 18. A relay R1 is operated by both dot and dash signals. The attraction of the armature at the beginning of a signal causes the capacitor C to be charged, and its release at the end of the signal causes the capacitor to be discharged. These charge and discharge kicks, taking place at the beginning and end of a signal, may pass through a short-circuiting contact SC or the windings of an alarm relay R2 according to whether the short-circuit is made or broken at that instant. The short-circuiting contact is controlled by a cam mounted on the main shaft of the re-perforator or the re-transmitter, breaking the contact once per signal element, and the contact mechanism is rotatable about the cam in order that its phase may be set relative to the selection point of the instrument. When the phase is correctly set, the contact is broken for a short period which embraces the selection point, and, should either end of the signal approach the selection point, the charge or discharge kick passes through the windings of the alarm relay R2 instead of across the short-circuiting contact. Fig. 19 (Plate 3) shows a practical case of the action of this device. Records are shown of the incoming and outgoing signals at a branch on a main-line circuit. The incoming signals, shown at (*a*), have been distorted by a sudden dash bias at the point indicated by an arrow, though the distortion is not sufficient to cause failure of the re-transmitted signals. The automatic scrutinizer has indicated the danger point by an increase in the size of the record of the outgoing signals.

The alarm relay R2 may be used to operate an alarm lamp or bell, to start up records, or to indicate on a record the faulty signal which caused it to be energized.

Channelling.

In recent years the number of non-loaded cables on which 2-channel systems have been installed, operating either at even or at uneven speeds, has grown considerably. The conditions which justify the use of channelling are: (i) when the normal speed of the chain, worked single channel, is too high for the satisfactory use of a printer; (ii) when cables capable of high speed are included in a lower-speed chain; (iii) when it is necessary to combine the signals of two lower-speed cables into one faster cable in an emergency due to cable interruptions.

Since all signals in cable code—dot, dash, and space—are of the same length, even speed channelling consists simply in allotting alternate signal periods to two separate transmissions. Two transmitters running at half aggregate speed are phased correctly and their marking periods are reduced to less than 50 % to provide the alternate transmissions. At an intermediate station the re-transmitter runs at aggregate speed and passes on the combined signals. At the terminal the signals are received on two re-perforators running at half aggregate speed, the selection points being phased into alternate signal periods. A re-transmitter may be substituted for one or both of these instruments by automatic switching, or permanently where channels are split into two separate cables. At the present time 16 cables are permanently channelled by this method, and apparatus is available for channelling during emergency on many more.

Channels bearing a simple speed relation to each other may be provided by adaptations of the even-channel methods described.

As previously mentioned, particular use has been made of uneven channels on the London–Rio de Janeiro and London–Buenos Aires chain, where the aggregate speed of the system as far as Ascension Island is capable of the combined speeds of the Ascension–Rio de Janeiro and the longer Ascension–Buenos Aires sections. Reception at Buenos Aires is limited by interference, a long length of the Ascension cable being laid in shallow water. Consequently it has been found economical to channel at speeds bearing the ratio 2 : 1 in the London–Rio de Janeiro–Buenos Aires direction and 3 : 2 in the Rio de Janeiro–Buenos Aires–London direction. The fast channel is known as the "A" and the slow as the "B"; thus with 2 : 1 ratio the cycle of unit signal periods allotted to the two transmissions is AAB, while with 3 : 2 ratio it is AABAB. Modifications of standard regenerator apparatus are necessary only at the terminal and splitting stations, as relaying stations on the chain pass on the aggregate signals only, picking out the signals of each channel for record purposes by means of cam-operated contacts. The divergence of channels, as in the London–Rio de Janeiro–Buenos Aires case, presents no difficulties as far as synchronization is concerned; on the other hand the combination of channels (as at Ascension in the Rio de Janeiro–Buenos Aires–London direction) can be achieved only by some " storage " system on one channel or by the speed control of the terminal transmitters from the outward signals, owing to the impracticability of maintaining identical speeds. The latter method is not very successful over long chains, as sway and consequent phase trouble are introduced.

" Storage " by re-perforation was first used, but the high operating costs led to the introduction of " capacitor storage."* With this method a margin for speed variation between the terminal transmitters is ensured by providing a loose link in one channel at the combining station through impulses stored in capacitors. Each incoming impulse from one cable is led into a capacitor by means of a distributor under the control of the signals on that cable, is stored, and is later picked up by a distributor under the control of the signals on the other cable, whence it is combined in correct sequence with the signals from the second cable. In the standard unit 60 capacitors are used, 30 for dots and 30 for dashes. Thus, if the storage is set in the centre of the margin available—i.e. a storage delay of 15 impulses—one terminal controlling clock may gain or lose a time corresponding to 15-unit signal periods with respect to the other before re-adjustment of the delay becomes necessary. In practice it is found that observation of the delay is required at the most once in about every 8 hours.

Variable-ratio channelling† has been evolved to meet the needs of a particular case where circuits of various speeds bearing no simple relation to each other are combined over a section capable of a speed equal to twice that of the fastest channel.

Improvement in speed control.

The method of bringing the speed of the reed under control of the clock has been described in a previous paper.‡ Briefly, any slight deviation of the reed speed is corrected by the angular displacement of a permanent magnet in relation to an armature carried at the extremity of the reed. The advent of increased speeds and of channelling showed that, although the average speed was maintained, sudden jumps would occur which had the effect of crossing channels during pauses in signalling. It was known that the addition of the permanent control increased the sensitivity of the reed to variations in the voltage of the supply, and this trouble was traced to momentary changes in voltage when a new bank of cells was switched on, and similar causes.

Investigation has shown that a relationship can be obtained between the natural frequency of the reed and the control exercised by the permanent magnet, whereby the change in reed frequency can be reduced to a negligible amount even when a variation as great as 5 % occurs in the voltage of the supply. The action may be described as follows: Considering the effect of a reduction in supply voltage on the reed alone, the amplitude of the reed vibration will become less and the frequency will increase. The presence of the permanent magnet produces the same effect, but in a degree depending on its angular position and its axial distance from the iron armature on the reed blade. Thus it is possible so to adjust the permanent magnet that, as voltage drop takes place, the resultant reduction of amplitude carries the reed out of the field of influence of the permanent magnet by precisely the amount necessary to counteract the increase of speed due to voltage drop.

A record of the behaviour of a reed when the voltage is varied is obtained by combining in the coil of a siphon recorder the output of the reed and that of a second one run from a steady supply during the trial. By this means a change in phase of the two reeds will be shown as an alteration in the amplitude of the siphon movement across the tape.

The specimens in Fig. 20 (Plate 3) obtained from trials carried out at a station show clearly in the first case the change of phase due to a 5 % voltage variation with the reed adjusted in the original manner, and in the second the steady running achieved by the new method of adjustment.

The direct printer.*

The direct printer already mentioned is now coming into use at terminal stations. The selection of the appropriate type bar and the printing of the character, immediately upon the reception of all the elements of the complete letter, eliminates the delay of 1–1½ minutes involved in the use of a perforated-tape-operated printer. The reception of a special signal combination will, however, bring a perforator into action when required for a message which has to be re-forwarded on another circuit.

The printer is designed to operate in conjunction with a synchronous system. Driving power is derived from a direct-current motor, but speed control is obtained from a phonic motor constantly phased to the incoming signals. When used with the regenerator system, the phonic motor is driven from the synchronizer unit in the same manner as a re-perforator.

Signals from the main circuit relays are fed to the printer without regeneration, the instrument itself performing this function. The formation of the character combinations is determined by three electromagnets on the selector head; one of these magnets is energized by dots, the second by dashes, and the third, called the spacing magnet, is energized by every impulse received, its function being to differentiate between signalling and spacing conditions.

Selection takes place once per unit signal period, the phasing of the printer being set so that selection occurs in the centre of each period. The presence of an impulse will cause the displacement of a dot or dash comb and, at the end of the character, the letter space causes the actuation of a spacing comb or gate permitting the exploration for the permutation set-up to take place.

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* British Patent No. 378090.

† British Patent No. 454276.

‡ H. H. HARRISON: *loc. cit.*

* This instrument is fully described in British Patent Specifications Nos. 463975, 463976, and 463977.

In the next unit period one exploring blade descends into its aligned slot, causing that particular combination to be stored in a slide. In this or the next unit period, depending on whether the printing shaft is geared for low- or high-speed operation, this slide is engaged by one of the type hammers and the character is printed.

A combination that is not printable is indicated on the printed copy by a plus sign, audible warning being also given when this takes place. The printer has attained a speed of well over 100 words per minute and may be constructed to print from either cable, morse, or equal-length codes.

Localization of Breaks and Faults

The older methods of testing for breaks—such as the Kennelly two-current test to false zero and Schaefer's scale-zero test—are now used as confirmatory tests upon the Lloyd and Lloyd–Black break tests.* Faults are still localized by the loop test where a second cable is available, and also by overlaps. Work has been carried out recently upon corrections to the overlap test with a view to minimizing errors due to low insulation. More accurate localization of high-resistance faults is thus obtained. Higgitt's loop method† of localizing high-resistance faults has proved of great use, particularly on underground landlines.

Records of the accuracy of the localization of faults, and breaks, taken by a large shore station having 12 cables of different lengths and characteristics, show that over a period of $3\frac{1}{2}$ years the average error, expressed as the ratio $\frac{\text{Error in ohms}}{\text{Resistance in ohms to break or fault}}$, is only 0·26 %.

Protection of Cables

With regard to the causes of breaks and faults, trawlers and corrosion are about equally responsible. It is hoped that a fair number at least of the trawler faults may be prevented by the use of the plough method developed by the Western Union Telegraph Co. Much will depend on the possibility of finding suitable paths for ploughing in various parts of the world, and also upon finding a successful method of dealing with crossings. To gain the greatest economy it should be possible to plough-in a light type of cable.

In dealing with corrosion the tendency is to concentrate upon protection of the armouring from contact with sea water. Corrosion is most active in warm waters; it is caused both by chemical constituents on the surface of the sea bed and by the products of marine growths which attach themselves to the cable. The galvanizing of the iron or steel wires is of protective value in proportion to the thickness of the coat. The coating specified by the British Standards Institution is considered too thin for the purpose, and as far as possible a more thickly coated wire is used. Under deep cold-water conditions galvanizing appears to be effective in protecting the armouring, whereas under the corrosive conditions mentioned above the zinc does not form a self-protective coat but appears to be dissolved at the rate of about 0·001 in. of thickness per annum. For this reason, as well as to protect the galvanizing from damage when being handled and to provide a higher coefficient of friction on the paying-out and picking-up drums, some form of strong adherent waterproof covering is required. Where causes of chafe are not present, smaller-diameter armour wires with a more efficient covering than was previously used are therefore being employed.

The galvanized wires, which must be weathered or produced with a matt surface, are tar-dipped and each wire is further protected by an impregnated cotton tape wound round it. After the formation of these covered wires into the armouring of a cable, the cable is covered with a serving of hessian tape having on its inner surface a covering of an inert waterproof substance; in the process of wrapping and compounding, the inert substance is forced into the interstices of the armouring. Applied outside the tape is a compounded serving of tarred jute. With this protection it is very difficult for the water to reach the galvanized iron or steel wire in such a way that circulation can take place to bring fresh corrosive products to bear upon the susceptible portion of the armouring.

Investigations into the cause of the reduction of the zinc covering of armour wires when cable is stored in tanks ashore and on ships, tend to show that the presence of sulphate-reducing bacteria is a likely source of the trouble. The irregularity of the incidence of this phenomenon would appear to support this theory. Active investigation of the subject is proceeding.

Duplex Balancing

Although from theoretical considerations there would appear to be little difficulty in obtaining a duplex balance upon a submarine cable, the practical conditions are such that the exact measurement of balance error, the calculations therefrom of the position and amount of corrections to the network, and their application and re-measurement, take so much time that the process becomes uncommercial. A skilled man can produce a good workable balance in a quarter of the time by rough observations of the balance error at various frequencies, and by using his experience in determining the alterations necessary to the artificial line.

Refinement of balances is progressing steadily as opportunities present themselves. Many balances have been obtained in the past by the use of a number of adjustments such as small resistors inserted between sections of the line, shunts over sections, etc. It has been found, however, that as a general rule the clearer an artificial line is of additional adjustments (known as fakes), i.e. the more nearly it is allowed to remain in its designed similarity to the cable as regards ratio of resistances to capacitance, the more stable the balance. Further, the art of obtaining a steady balance lies in the accurate application of adjustments which will cause the inductance of the cable (which decreases with frequency owing to the return current through the earth closing-in on the cable) to be imitated in the combination of resistance and capacitance in the artificial line. These adjustments consist of the insertion of resistors between certain groups of capacitors near the beginning of the line and the earth.

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* *Electrician*, 1919, vol. 83, p. 498.

† *Ibid.*, 1921, vol. 86, p. 96.

One of the main difficulties in the determination of the values of the resistors and their exact location lies in the want of homogeneity of the cable as regards the ratio of resistance to capacitance. As the cable system was extended the copper conductors became larger and larger in order to obtain greater speed. As it is quite impossible to stock all these types for repair work the portions near the end of a cable, where repairs are most frequent, often consist of a patchwork of different types. This enhances very much the difficulties in the application of calculated values, since compromises have to be effected.

Many attempts have been made to put balancing on a scientific basis. A few years ago D. C. Gall made an investigation of the problem and evolved a method based on a.c. measurements.[*] The principle of this method proved to be sound, but for the practical reasons given above it has not been adopted.

Instances of recent increases of speed, due, in the main, to refinement of balance, are given in Table 1.

Table 1

Cable	Signal elements per minute	Increase
Aden–Colombo . .	from 846 to 1 019	20 %
Colombo–Penang No. 1	from 1 250 to 1 413	13 %
Porthcurno–Gibraltar No. 4 . . .	from 1 412 to 1 693	20 %
Porthcurno–Madeira .	from 1 114 to 1 500	34 %

(7) WIRELESS TELEGRAPHY

General

The five transmitting stations and four receiving stations controlled by the operating company in England are shown in Fig. 43 (Appendix 2). The telegraph and facsimile circuits handled by these stations are set out in Table 2.

Table 2[†]

Destination	*Transmitting station*	*Receiving station*
Bangkok	Dorchester	Brentwood
Belgrade	Ongar	Brentwood
Berne	Ongar	Brentwood
Beyrouth	Dorchester	Brentwood
Bogata	Dorchester	Brentwood
Bombay	Tetney D	Skegness
Buenos Aires F	Dorchester D	Somerton
Cairo	Dorchester D	Somerton
Cape Town	Bodmin D	Bridgwater
Falkland Island	Dorchester	Brentwood
Las Palmas	Ongar	Brentwood
Lisbon	Ongar	Brentwood
Madrid	Ongar	Brentwood
Maracay	Dorchester	Brentwood
Melbourne	Tetney D	Skegness
Melbourne	Ongar D	Somerton
Melbourne F	Ongar D	Somerton
Montreal	Bodmin	Bridgwater
Moscow	Ongar	Brentwood
Nairobi	Ongar D	Brentwood
New York	Carnarvon	Somerton
New York F	Dorchester D	Somerton
New York	Ongar D	Brentwood
Paris	Ongar	Brentwood
Rio de Janeiro	Dorchester D	Somerton
Salisbury	Ongar D	Brentwood
Santiago	Dorchester	Brentwood
Shanghai	Dorchester D	Somerton
Shanghai	Ongar D	Somerton
Sofia	Ongar	Brentwood
Sofia	Carnarvon	Brentwood
Stamboul	Ongar D	Brentwood
Teheran	Ongar	Brentwood
Teheran	Dorchester	Brentwood
Tokio	Dorchester D	Somerton
Tokio F	Ongar D	Somerton
Vienna	Ongar	Brentwood

All these circuits terminate in London. The majority of the links between the nine stations and London consist of underground land cables worked on a tone-channel system; and only a few physical circuits are retained. The London ends of the lines are terminated in a control room where the circuits are monitored and distributed to the various sending and receiving positions in the main instrument room.

The majority of the wireless circuits are worked by automatic transmission and manual reception, operators being employed to transcribe the undulator signals into typewritten script. On certain circuits, however, automatic reception using regenerator methods is possible. A description of these is given in a later section of this paper.

Wireless messages at an originating station such as London are normally prepared in the form of a perforated tape and are fed through a Wheatstone transmitter, the impulses from which operate a relay in the control room. This relay controls one of the outward tone channels to the selected transmitting station, where the signals are filtered and made to key the appropriate transmitter by means of either a valve or a relay circuit. At the control switchboard of the transmitting station are lamp devices which give an immediate indication, both audible and visible, when the transmitter fails to emit a signal from the line.

At a receiving station the homeward tone channels are normally controlled by the incoming signals without the use of relays, and thus a possible source of local noise is eliminated.

Automatic reception is employed on several important circuits. The system used has, to a large extent, the detectability of error enjoyed by cable code. The circuits are usually worked with two channels on a time-basis system, the elements of the channels being interleaved. The code used is similar to the double-current cable code described previously, but after a period of quite successful working with the normal double-current cable code it was found that the code could be modified with advantage for use on wireless circuits. These modifications are described later.

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[*] British Patent Specifications Nos. 262991, 301340, and 302474; also *Electrician*, 1920, vol. 85, p. 736.

[†] A directional aerial is indicated by D and a facsimile circuit by F.

On the circuits which are worked with regenerator methods poor conditions are covered by making use of the Verdan principle. Both channels carry the same signals, but one set is delayed at the transmitting end by capacitor storage and the other set an equal amount at the receiving end. The delay is usually set at 2 seconds, since this period has been found to cover the majority of short fades and atmospherics.

The increase in the number of wireless services operated during recent years is indicated on the maps in Appendix 2.

The accumulation of information on working conditions has led to steady progress in the methods of operating the various services; and prolonged tests on the majority of circuits have enabled the best types of aerials to be selected to suit particular conditions. In this connection progress has been mainly in the modification of standard designs and the use of more efficient directional aerials.

In co-operation with manufacturers, marked improvements have been effected in the design of transmitters, particularly in the direction of controlled-frequency drive, giving increased stability of transmitter frequency and permitting the use of more selective receivers. Unbalanced absorber keying, in which only a portion of the power used on " mark " is absorbed by the keying circuit during " space," is extensively adopted. Sufficient power only is absorbed on the space signal to cut off radiation and at the same time to keep keying reactions on the supply system down to a reasonable figure. The resultant saving of power is considerable.

In special cases methods of frequency modulation are used for overcoming fading troubles.

Verdan working, while catering for the elimination of either fades or extras, cannot deal with conditions where both these factors are present at the same time. Recently experiments have been carried out on " double frequency keying,"* by means of which the intelligence is in effect conveyed twice by one transmission. This method includes means by which all types of interference may be converted into a single form of mutilation (e.g. fades), as is required for automatic repetition of signals by the Verdan system. Considerable work on similar methods has been carried out elsewhere,† but the practical results achieved so far have been limited.

A further advantage of the double-frequency system is that the normal cable code can be used in place of the double-current cable code. A full description of the methods adopted is given later, together with circuit drawings. Means for automatically adjusting the receiving oscillator frequency, employing the magnetic-clutch mechanism fitted on cable relays, are also described. It will be appreciated that the problems of frequency control are considerably greater on a telegraph circuit than on a telephone circuit, since a pause in signalling may mean a complete cessation of signal, during which control is inoperative. In addition, owing to the closeness of the frequencies used, double-frequency keying has called for greater stability of heterodyne in receivers.

Receiver design as a whole is as up to date as possible, automatic gain control, modified limiter circuits, etc., being used generally. For ships' services such details as automatic searching over a band of, say, 595 to 605 metres are of interest.

Normal diversity reception is adopted where justified by considerations of space and cost.

Dual reception of two wavelengths (i.e. frequency diversity as opposed to space diversity) is also used, but is a more expensive method, as two distinct transmitters are required. Where spare apparatus is available the main use of dual transmission and reception is to maintain a continuous service during times at which a change of wavelength is made.

The main circuits, both transmitting and receiving, retain the Franklin vertical beam aerial in a modern form; no other form of aerial has proved to be equally effective, having regard not only to signal fields but also to signal/noise ratios and to the reduction of echo. This is of extreme importance during maximum sunspot years. Considerations of cost, however, have led to the adoption of the Franklin series phase aerial on many recent circuits. Rhombic aerials and other types are used in certain cases.

A general policy of separate transmitting and receiving sites has been followed, owing to the multiple services required, such as ships' services, direction-finding for ships and aircraft, fixed telegraph services, and radiotelephony. Reasons of economy in buildings and staff, however, have led to the adoption of common site working of wireless and cable circuits in certain cases. This arrangement has raised many problems, including the suppression of " noise " created by the cable apparatus, the provision of remote control of transmitters for starting up and shutting down, and the use of automatic wave-change switches.

Centralization of a number of services at one receiving or transmitting point has given increased flexibility with the aerial systems available. Thus during maximum sunspot years the London–Buenos Aires circuit may become unworkable for many hours over the direct route with the normal wavelengths available. However, advantage can be taken of the Tokio aerial systems at London and Buenos Aires to work over the long route, where such wavelengths may be usefully employed. The necessity of installing additional aerial systems is thus avoided. Similar use is made of other aerial systems, such as London–Bangkok and London–Maracay.

Cosmic data are carefully correlated with transmission and reception conditions, enabling the most efficient use of wavelengths to be made to suit the changes in the solar cycle. A few typical data charts are shown later in the paper. A continuous check is also kept at Brentwood on transmitter frequencies, upon both the company's and other transmitters.

Double-current Cable Code, and Method of Operation on Wireless Circuits

The double-current cable code, already described, was found to have some disadvantages when used on a wireless circuit, as comparatively long periods of spacing signal were possible when no signal was transmitted. Thus on a circuit working with two even-speed channels a figure 0 on each channel might result in a quiescent period of 10 unit time-intervals. In certain circumstances this introduced difficulties with regard to the gain-control apparatus at the receiving wireless station. There was also a tendency for atmospherics and quick fades to turn dashes into dots, and vice versa.

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* British Patent No. 480289.

† A. Bakker and H. C. A. Van Duuren: British Patents Nos. 388625 and 419526.

As the result of suggestions made by R. Bruford the code was therefore modified in such a manner that the longest possible unbroken space periods and the longest possible unbroken mark periods have been reduced to 2 unit time-intervals. Referring to the two channels as Channel A and Channel B, on Channel A a dot consists of 50 % space followed by 50 % mark, a dash consists of 50 % mark followed by 50 % space, and a space signal of 100 % space. On Channel B a dot is the same as the Channel A dash, a dash the same as the Channel A dot, and a space signal consists of 100 % mark. Combined channel signals are illustrated in Fig. 21(*a*), the A channel transmitter signalling the letters AA and the B channel transmitter the letter B. Thus the first signal period shown consists of a dot from the A transmitter (space/mark), the second signal period is a space from the B transmitter (100 % mark), the third a dash from the A transmitter (mark/space), the fourth a dash from the B transmitter (space/mark), and so on.

The signals are received on synchronous regenerator apparatus similar in principle to that used on the cable circuits, but owing to the necessity of uneven selection points a cam-and-contact method of selection is substituted for the mechanical selection of the cable apparatus. These selection points are shown in Fig. 21(*a*), and the resultant regenerated channel signals in Figs. 21(*b*) and 21(*c*). In each case the dashes are delayed, after selection, by capacitor storage to bring them into phase with the dots. The A channel signals are selected during the marking periods and the B channel signals during the spacing periods, with the result that the possibility of a dot being changed into a dash, or vice versa, by atmospherics or fades is considerably reduced. The suppression of half a dot or dash signal will result in the signal being dropped. The spaces may, of course, be mutilated and be changed into a dot or dash, but this change should be readily detectable.

The code also adds to the secrecy of wireless messages. Fig. 22 (Plate 3) illustrates this point. A record of signals received on the Bombay circuit is shown, together with the separated channel signals. For clarity, 50 % channel signals are shown.

The regenerated channel signals operate relays which normally actuate a perforator feeding into a tape printer. In special cases, calling and switching devices are operated and the signals fed into re-transmitters. The direct printer, already described, will shortly be in use on these circuits.

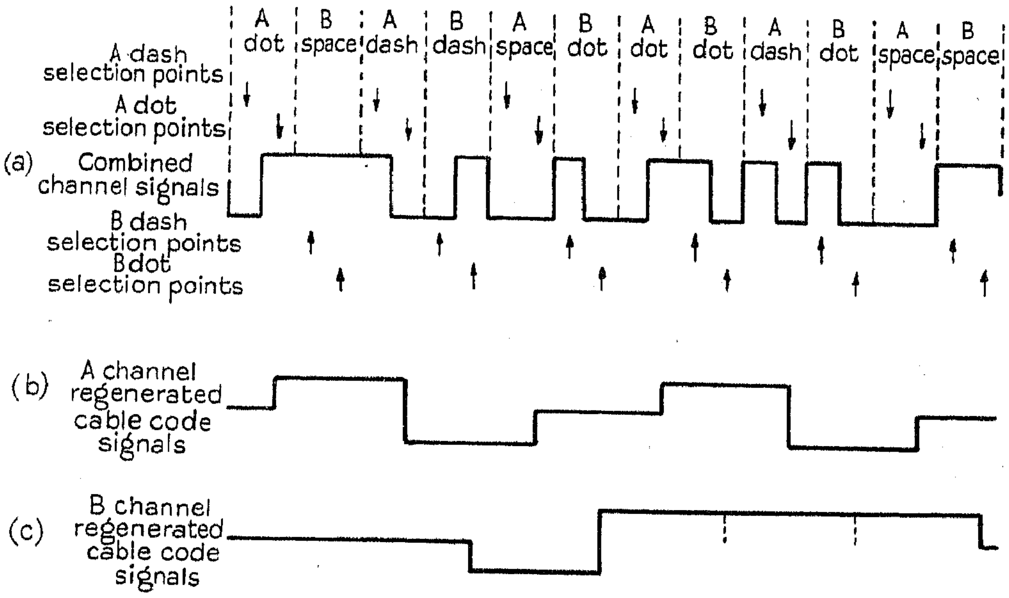

Fig. 21.—Double-current cable code signals on wireless.

Transmitting-Station Monitor

The wireless transmitting-station monitor is included in this paper as an example of a number of warning devices incorporated in both wireless and cable circuits. The device is designed to provide a warning in the event of improper operation of the transmitter under conditions where the usual protective apparatus would fail to function.

A differentially wound relay is arranged with one winding energized from the transmitter keying circuit and the other from the radio check circuit. The inputs from the two circuits are adjusted to balance, but if the radiation fails to follow the telegraph signals, or varies in value, the balance is destroyed and the relay operates to ring an alarm bell. The device will give warning in the event of an aerial or feeder fault, failure of any one valve in the magnifier stages, and failure or partial failure of the auxiliary rectifiers for the magnifier stages.

Various methods of connecting the relays are possible, and the choice must depend on the system of line working and of keying the transmitter. The most generally applicable method of energizing the winding (A) which is operated by the incoming line signals is to key a valve whose grid circuit is joined in parallel with that of the sub-absorber, the line winding of the relay being in the anode circuit (Fig. 23). The monitor is then independent of the method of line working or transmitter keying and does not appreciably increase the current across the keying-relay contacts, while the working current in the monitor relay winding is not in any way controlled by current values required in other circuits.

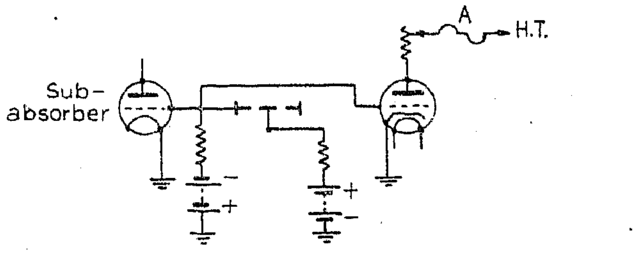

Fig. 23.—Transmitter monitoring relay: line winding circuit.

The second winding (B) of the differential relay—the winding energized by the radio signals—is normally joined in series with the resistors of the radio pick-up circuit. The pick-up is adjusted to give a current through this relay winding which balances that flowing in the line winding in the mark-valve anode circuit of the valve keying unit. Fig. 24 shows the connections, and the type of radio pick-up used. The relays are fitted with change-over contacts. These are joined up to show a green light under normal conditions and to ring an alarm bell and show a red light when the relay operates.

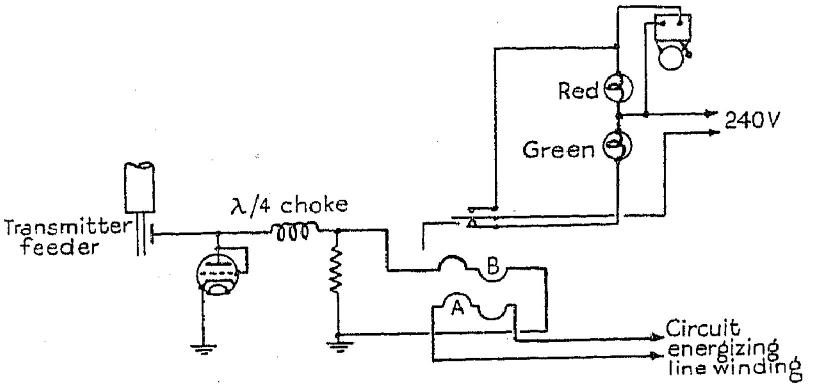

Fig. 24.—Transmitter monitoring relay: circuit of radio pick-up winding.

Keying a Tone Channel on a Landline Circuit from a Wireless Receiver

Many methods are in use for keying a tone channel on a landline circuit from the received wireless signals. Keying circuits have been improved steadily with a view to "cleaning up" the wireless received signals and reducing distortion due to multiple-ray and similar effects. Fig. 25 shows an improved type of tone-sender circuit. After the signals have been rectified in the receiver they are passed through two limiting stages, the first of which has provision for bias correction (i.e. a $0{\cdot}01$- to $0{\cdot}1$-μF variable capacitor C), and the second of which is necessary to reduce the sloping front of the signal resulting from the bias correction. The anodes of the oscillator and the second limiter stage are fed through a galvanometer to give a bias indication, balance being obtained by means of a variable resistor in the second limiter anode. The actual tone-sender portion of the unit is similar to the band-pass tone-sender normally used, except that battery valves are employed.

Such tone senders can be grouped at a convenient point away from the receivers, for it is found that the extension leads produce no appreciable interference and that the capacitance of the maximum lengths of leads likely to be required has a negligible effect on the signal bias. The oscillator keying wave-form is square, and any malformation of the wave-form due to the action of the bias-correction capacitor is not reflected in the oscillator anode. As the output wave-form of the oscillator is square, the listening point before the filter may be used as a checking point for the existing audio-frequency check bridges.

Double-frequency Keying of Wireless Transmitters

The following is a description of a method, at present being developed, of operating short-wave wireless communication channels with a view to providing means by which all types of interference may be converted into one form of mutilation (e.g. fades) as required for

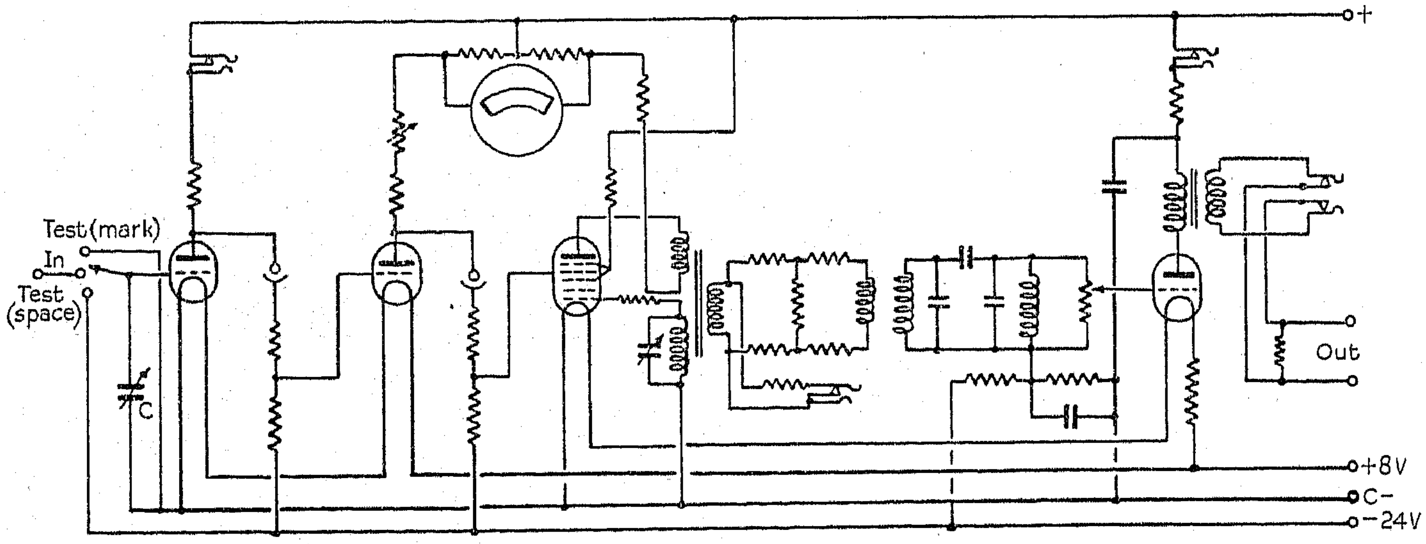

Fig. 25.—Valve-keyed tone sender.

automatic repetition of signals by the Verdan system. These developments have the ultimate object of enabling the direct printing of messages to be adopted on all main wireless circuits.

Transmitter.

The transmitter (Fig. 26), which, following the conventional design, includes a master oscillator (M.O.) for driving the main amplifier at the required frequency, is arranged to emit either a spacing or a marking frequency (differing by about 600 cycles per sec.) in accordance with the position of the tongue of the control relay. For example, when the position of the relay tongue is such as to make the first valve conductive, the second valve—a diode—is arranged to be non-conductive, the frequency of the master oscillator being then substantially unaffected by the small capacitor plate C. In the other position of the relay tongue the first valve is non-conductive and the diode is then conductive, with the result that the plate C reacts on the master oscillator in such a manner as to produce the desired frequency-change. Although this frequency-difference is capable of accurate adjustment, the receiving apparatus as described permits a variation of ± 15 % to ± 20 % of the mean setting.

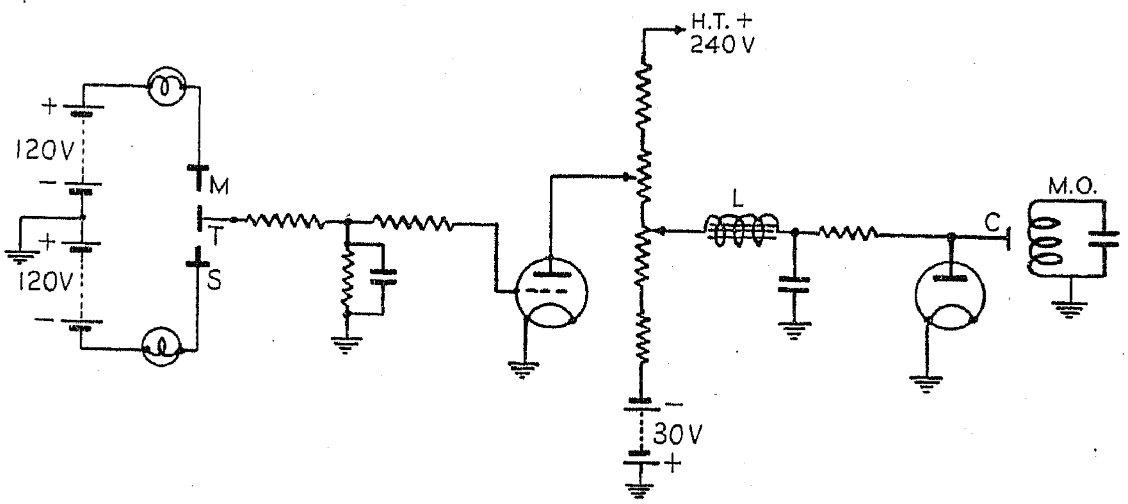

Fig. 26.—Double-frequency keying system: transmitter.

Receiver.

The receiver, which may be of either the superheterodyne or the "straight" type, includes the following features in addition to an audio-frequency amplifier and high- and low-pass filters for amplifying and separating the mark and space signals:—

(*a*) Automatic gain control of the earlier stages of the receiver, comparable in degree with that used for reception of telephony.

(*b*) A combiner unit for automatically operating the output relay by the mark and/or space signal, (i) under conditions of reception where one or other frequency is completely absent owing to selective frequency fading, or (ii) where the degree of fading (or interference) is excessive, in such a manner as to convert all types of mutilation into one form (e.g. fades).

(*c*) Automatic frequency control of the first heterodyne circuit so as to maintain sensibly constant the beat frequencies in the high- and low-pass filters.

Fig. 27 gives a schematic diagram of the receiver. The high-frequency amplifier, intermediate-frequency amplifier, audio-frequency amplifier, and second heterodyne are of conventional type and call for no special comment. The remaining portion of the receiver is peculiar to the special type of signalling, and will therefore be dealt with in greater detail.

The output of the audio-frequency amplifier contains the mark and space signals, and operates (*a*) into a double-wave rectifier for securing automatic gain control of the high-frequency and intermediate-frequency amplifiers; and (*b*) into high- and low-pass filters to separate the mark and space signals. These in turn operate into the combiner unit and automatic frequency-control unit, the latter being preceded by suitable band-pass filters.

Combiner unit.

As will be seen from Fig. 28, the combiner unit consists of a rectifier (V1, V4), a limiter (V2, V5), and a coupling stage (V3, V6) for each signal (mark and space), the coupling stages being interconnected by a "dead-beat" multivibrator (V7, V8), the anode circuits of which carry the coils of the output relay.

The multivibrator connected in this manner can be controlled (i) by the mark signal alone, (ii) by the space signal alone, the form of connection being such that the signals are automatically reversed by the multivibrator so as correctly to control the output relay, (iii) by both the mark and space signals simultaneously. Moreover, atmospherics or other interference joining together characters of one signal will, in the presence of the other signal, leave the output relay undisturbed. Such signals are shown in Fig. 29.

It will be seen that, since the gain of the high-frequency and intermediate-frequency amplifiers is controlled by either the mark or the space signal, whichever is the stronger under conditions of "selective frequency fading," the receiver will operate on "peak" signals. Normally, therefore, a degree of protection from interference and cross-modulation and from overloading of the receiver is secured. Certain types of interference, e.g. a partial fade of any particular signal element as distinct from complete absence of signal, may produce faulty operation of the output apparatus. Therefore, in practice, a certain degree of frequency modulation on both the space and mark signals is desirable, which

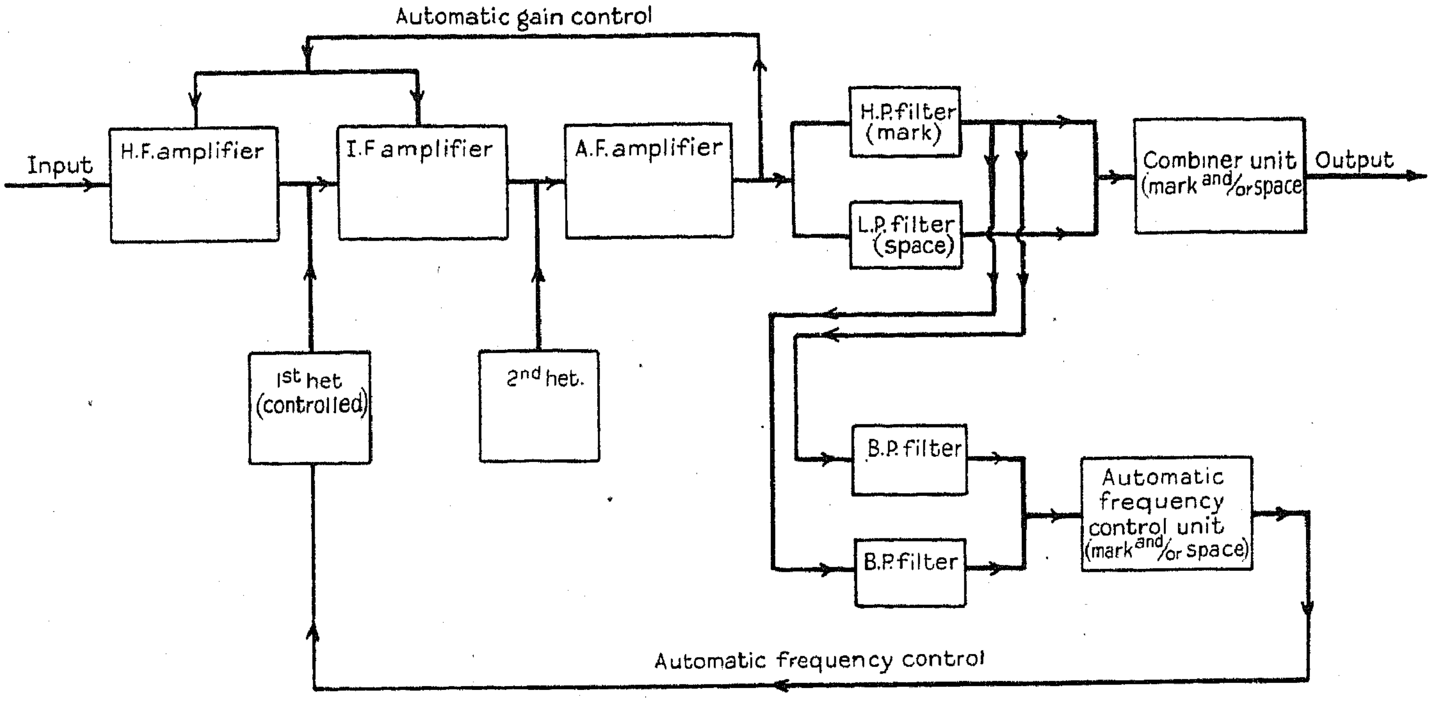

Fig. 27.—Double-frequency keying system: receiver.

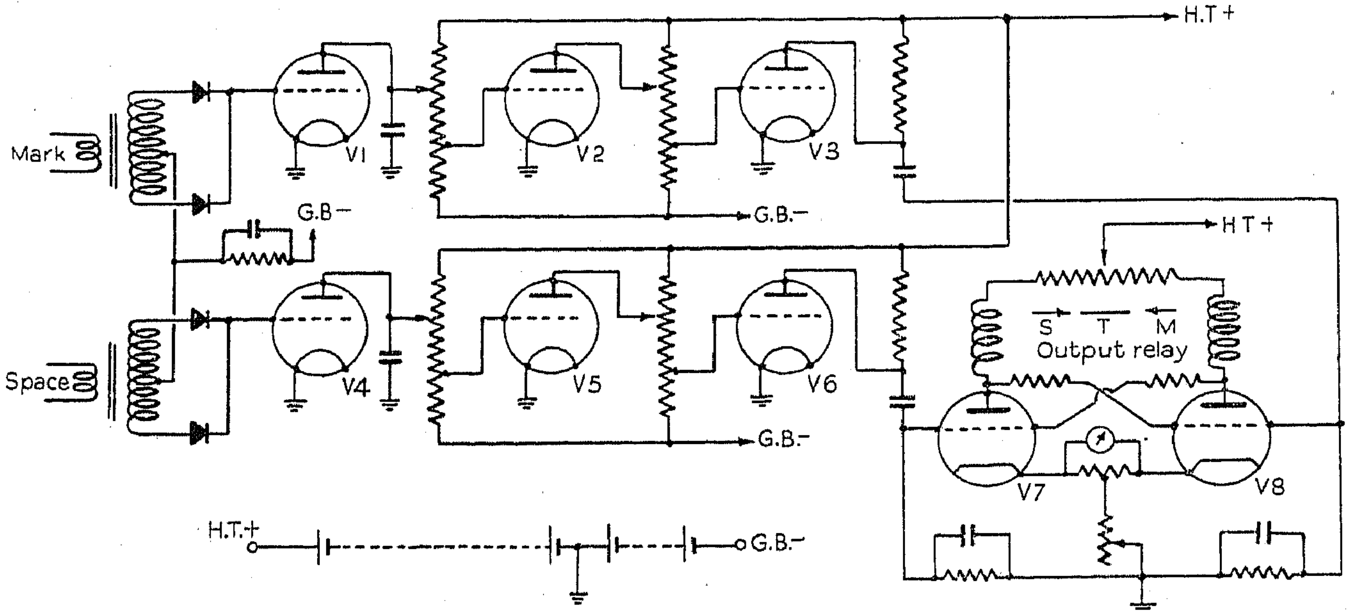

Fig. 28.—Double-frequency keying system: combiner unit.

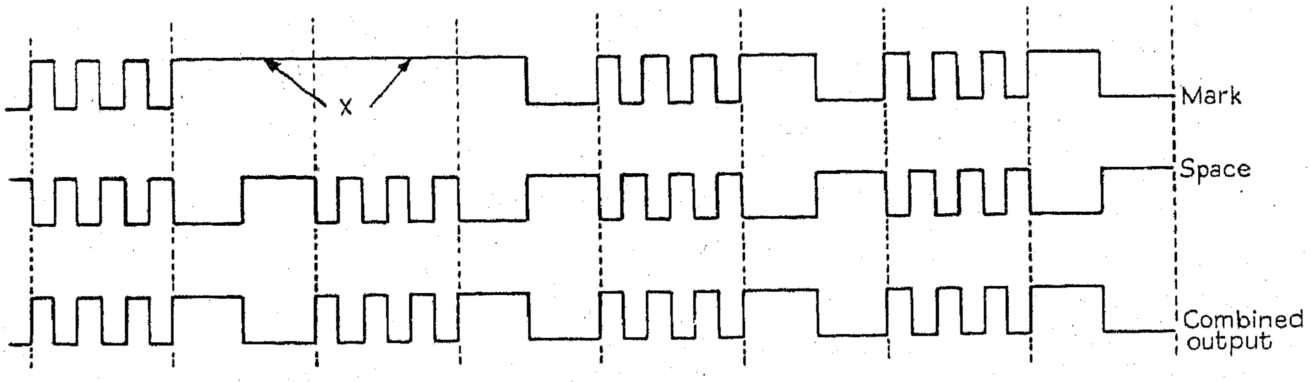

Fig. 29.—Combined signals.

in turn necessitates a somewhat larger difference of mean frequency of these two signals.

When the field intensity of the peak signals becomes too low to permit satisfactory printing, the connection of the combiner unit may be modified by switch operation so that a mark is recorded only when the mark signal, as received, is *on* and the space signal *off*. Under all other conditions (e.g. fading or mutilation of either frequency channel, or a correctly received space signal, i.e. space *on* and mark *off*) a space is recorded. By this means automatic repetition of signals on the Verdan principle will cater simultaneously for atmospherics and fades.

A convenient method of modifying the combiner unit for this purpose is to disconnect the anode of valve V6 (Fig. 28) from its resistor-capacitor combination and connect it to the anode of valve V2, the multivibrator then being actuated only by valve V3.

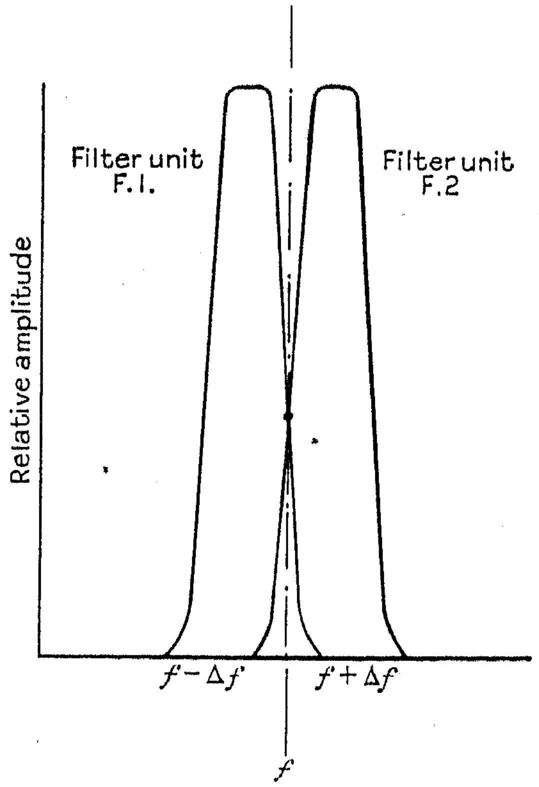

Fig. 30.—Response curves.

Under these conditions valve V3 will be conductive and a mark recorded only when valves V2 and V6 are non-conductive, i.e. the mark signal *on* and the space signal *off*. Under all other conditions a space will be recorded. Alternatively, the same effect may be obtained by the introduction of a multi-electrode valve, in which Grid 1 is controlled by the mark and Grid 2 by the space signal.

Automatic frequency control of receivers.

On the receivers a form of automatic frequency control is used which is applicable equally to telephony, to double-frequency keying, and to the normal type of telegraph transmission in which there are quiescent periods during signalling.

The receiver oscillator is adjusted in the first instance so as to produce, either directly, or indirectly in conjunction with one or more auxiliary oscillators, a beat frequency *f* (Fig. 30). Energy at this frequency is passed through two discriminating filters F1, F2 (Fig. 31), the outputs of which are connected to two a.c./d.c. convertor units. The output circuits of the latter consist of valves (V3, V6) and anode coils (C1, C2), the H.T. supply being either alternating current or interrupted direct current. The coils C1 and C2 form the windings of the electromagnets of a magnetic-clutch mechanism as described in connection with the bias-correcting unit shown in Fig. 13(*b*). In this case the threaded main spindle attached to the clutch disc of the corrector controls the position of a capacitor vane E1. A sectional drawing of this mechanism is shown in Fig. 32.

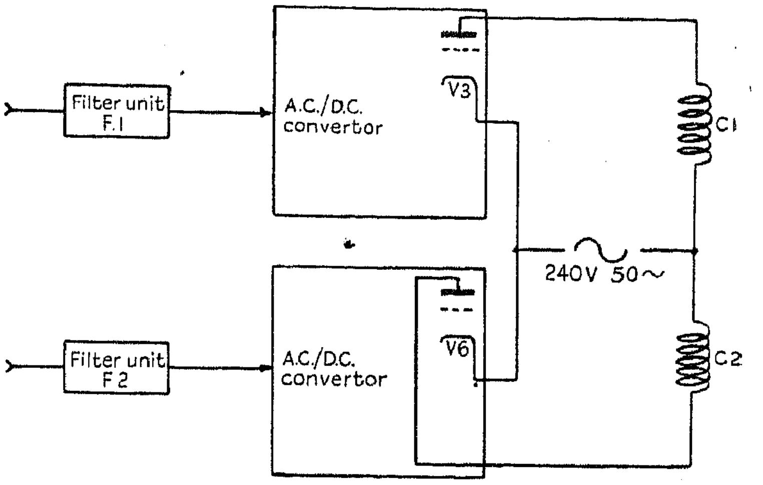

Fig. 31.—Automatic frequency control.
C_1, C_2 are bias-corrector electromagnets.

When a magnet is energized as a result of one of the output valves being made conductive, the resultant field passes through the adjacent soft-iron portions of the armature spider and the portion of the clutch disc between them. The armature is pulled against the disc and towards the magnet poles simultaneously, causing the disc to move with the armature. When the armature current ceases and the field collapses, the armature is returned to its central position by control springs, but as it is no longer attracted to the disc the latter and the capacitor vane are left in their new position. The above cycle of operations continues, as a result of the interrupted nature of the current in the output valve, until such time as the valve is rendered non-conductive.

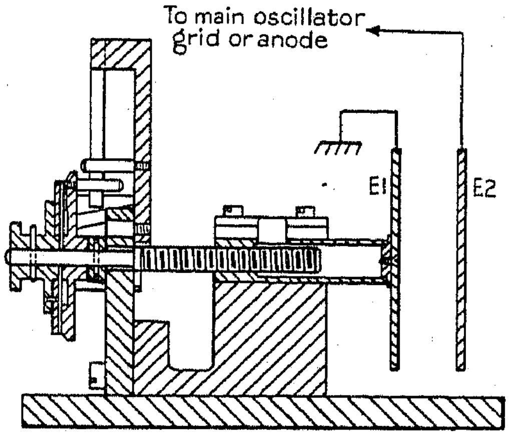

Fig. 32.—Automatic frequency-control mechanism.

With the receiving oscillator adjusted so as to produce a beat frequency *f* through the filters, the output valves of the a.c./d.c. units are adjusted so as just not to conduct. Any tendency for the beat frequency to change is accompanied by an increase of current through one unit, causing its ouptut valve to conduct and resulting in the operation of the magnetic clutch and therefore the capacitor vane E1, the direction of movement depending upon which of the output valves is actuated. The resultant change of the capacitance of E1 E2 is arranged to react on the constants of the oscillator (Fig. 27) so as to effect the necessary change of frequency for the desired constant beat frequency *f*.

Satisfactory operation of the corrector can also be obtained by initially setting the output valves to conduct and by balancing the resultant flux set up in each coil. The arrangement described above is, however, preferable. The range of correction can be varied between wide limits in accordance with the size of the variable capacitor and the sensitivity of the a.c./d.c. convertor units.

As an alternative to the method indicated in Fig. 31 for obtaining the interrupted nature of current in the coils C1 and C2, the H.T. supply may be direct current and the coils C1 and C2 may each form part of an oscillatory circuit associated respectively with the valves V3 and V6, the oscillation amplitudes of which may be varied differentially in accordance with the tendency of frequency *f* either to increase or to decrease.

For the reception of double-frequency signals the correction is applied to one only of the two frequencies (mark or space).

If, at the transmitter, an elementary oscillator be used in conjunction with the master oscillator—the one for mark and the other for space—and if the difference frequency be maintained constant in the manner described above, the resultant beat frequencies in the output stages of the receiver will be constant and can therefore be used in association with narrow-band filters, with consequent improvement of signal/noise ratio.

Effect of Cosmic Conditions on Wireless Telegraph Circuits

A vast amount of data is collected regarding the conditions of working on all the main wireless circuits in order that the best methods may be evolved to suit each particular circuit, and also that some attempt may be made to predict the conditions likely to be met in the future. The following two examples are illustrative of this work.

Effects of solar cycle.

The optimum wavelengths for any given route are dependent upon the season and the time of day; an additional and important factor is the degree of solar activity, which follows approximately an 11½-year cycle. The last sunspot maximum period was in 1928–29, and the minimum period in 1933–34. The years following the latter period have been accompanied by a marked increase in activity, which on a half-yearly basis exhibited a well-defined peak for January to June, 1937. Records for the past 100 years reveal that, whilst the average length of cycle was 11·4 years, the change from minimum to maximum activity occurred over an average period of only 4·5 years; a study of wireless data for the year 1938 indicates that it is not improbable that the year 1937 may prove to have been the maximum peak of the present cycle.

As an example of the effects of the cycle on short-wave communication, the curve of Fig. 33(*b*) shows hours during which a wavelength of 16 metres proved usable on the London–Bombay route for the period 1930–38 for the months centring on the equinoxes (i.e. February to April, August to October, inclusive), whilst Fig. 33(*a*) indicates the average sunspot activity for the same years. The correlation is less pronounced at the opening of the route (AA′) than at its closing (BB′), owing to the fact that the rate of ionization associated with sunrise is considerably greater than the rate of recombination around sunset. The change in conditions resulting from a change in activity is still more pronounced for routes in higher latitudes, and Fig. 34 shows the percentage time of each day for which the 16·5- and 69-metre wavelengths were employed on the London–Montreal circuit in the years 1934 and 1937. The intermediate wavelengths are omitted for the sake of clarity. It will be noted that increased activity, with its accompanying increase of ionization, enhances the utility of the shorter wavelengths.

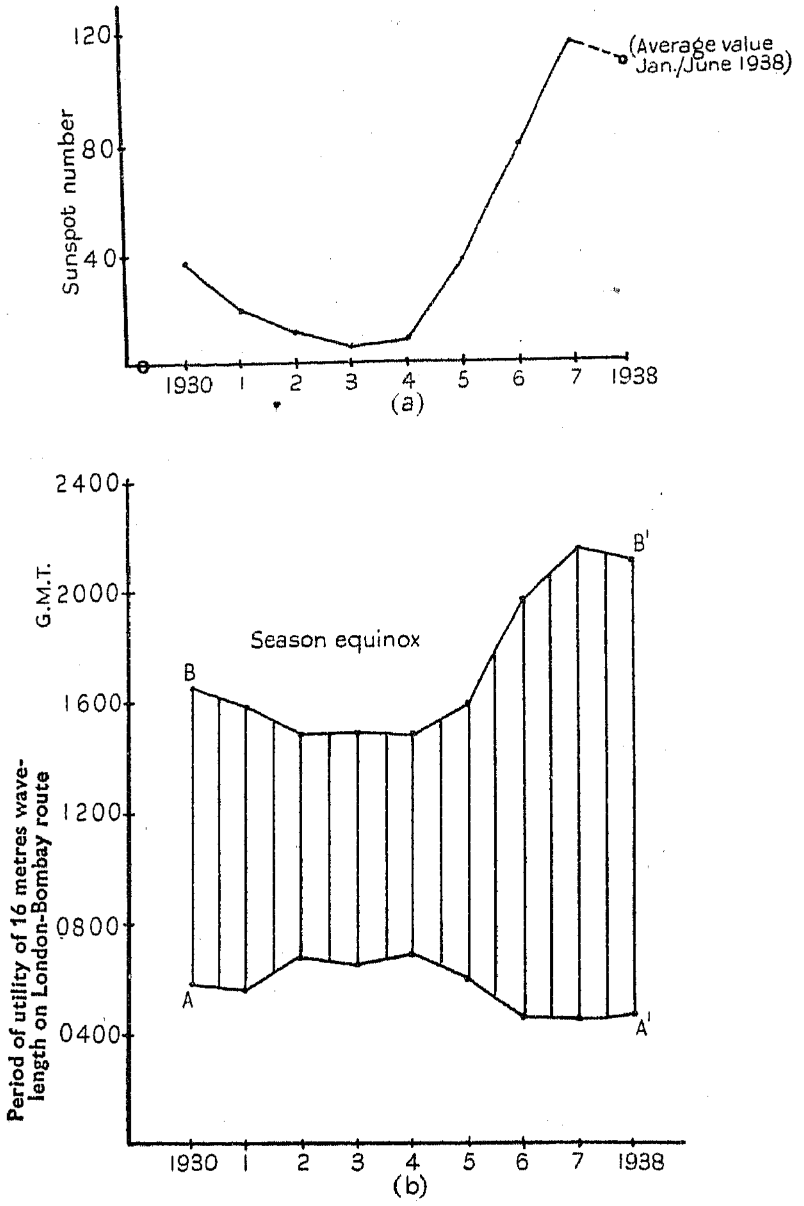

Fig. 33.—Effect of sunspot activity on utility of 16 metres wavelength on London–Bombay circuit.

Echo.

At certain times and seasons, attenuation of wireless signals may be so low over both the major and minor arcs of the great circle embracing the two terminals that signals may arrive both by the forward and by the backward route, and even encircle the globe some two or three times. As an example of these conditions, Fig. 35 (Plate 4) shows the reception at Bridgwater of two consecutive dots transmitted from Cape Town (A_1), together with a sequence of three echoes—B_1, C_1, and D_1—of the main transmission, as a result of the rays encircling the globe three times. During the interval A_1A_2 the transmitter was quiescent, after which the transmission of two more dots produced a similar sequence of echoes. The distortion of the pair of dots A_1A_2 received over the relatively short direct path is attributed to the reception of multiple signals, to which the route is known to be susceptible at the time and season in question. The echo pairs tend to become progressively "thinner" as the steeper-angle multiple rays become more and more attenuated with increasing distance, reception of the later echoes being confined substantially to shallow-angle rays.

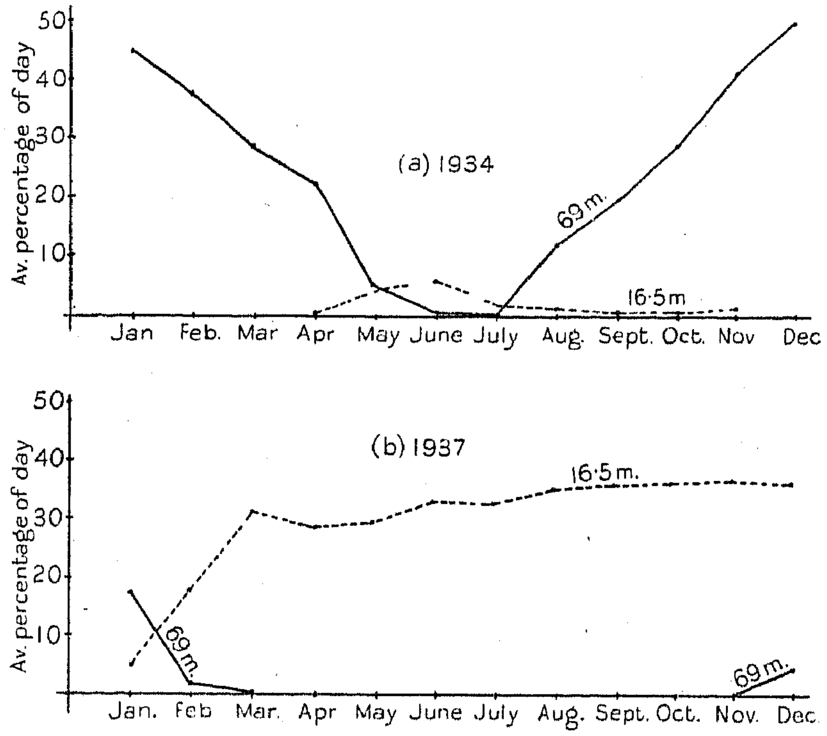

Fig. 34.—Extreme wavelengths used on Canadian beam.

A further example of such phenomena is indicated in Fig. 36(*a*), Plate 4, where a similar transmission (i.e. two consecutive dots 1, 2, repeated at regular intervals, originating in this instance at Bombay) resulted in the reception at Skegness of additional signal elements 3, 4, and 5. In this case the mutilation was caused by a combination of forward and backward echo, the speed of signalling being such that five equally-spaced dots were produced at the receiver, the individual pairs of dots being as shown in Fig. 36(*b*). The delay period of the forward echo is of the order of 0·14 sec., and the difference between the lengths of the forward and backward routes is such as to produce a delay of about 0·09 sec. on the backward echo. The ratio of these two delays is seen to be substantially equal to the ratio Y/X, i.e. 1·5.

It should be emphasized that the above records were obtained under test conditions, i.e. with the receiver adjusted to maximum sensitivity and the automatic gain controls removed, the purpose of the tests being to disclose the presence of any abnormal route conditions. In practice, the direct signals are generally so much stronger than the auxiliary ones that automatic gain control and similar methods can be satisfactorily used to reject partially, if not completely, the unwanted signal components.

ACKNOWLEDGMENTS

In conclusion, the author desires to acknowledge with thanks the courtesy of Cable and Wireless, Ltd., in giving permission for the production of this paper, and also the assistance of his staff, with particular reference to Mr. W. L. Langford, Associate Member, and Mr. A. M. Humby.

APPENDIX 1

Detailed List of Companies and Systems Incorporated in the Communications Operating Company, and Companies Associated with the Group

Eastern Telegraph Co., Ltd.: Group including Eastern and South African Telegraph Co., Ltd., Europe and Azores Telegraph Co., Ltd., West African Telegraph Co., Ltd., African Direct Telegraph Co., Ltd.
Western Telegraph Co., Ltd.: Group including West Coast of America Telegraph Co., Ltd., Pacific and European Telegraph Co., Ltd., London Platino-Brazilian Telegraph Co., Ltd. (liquidated), River Plate Telegraph Co., Ltd.
Eastern Extension Australasia and China Telegraph Co., Ltd.
Marconi's Wireless Telegraph Co., Ltd.
Direct Spanish Telegraph Co., Ltd.
Indo-European Telegraph Co., Ltd. (liquidated).
British East African Broadcasting Co., Ltd. (liquidated).
Indo-European Telegraph Department (now non-existent).
Société Anonyme Belge des Cables Télégraphiques.
Direct West India Cable Co., Ltd.
Halifax and Bermudas Cable Co., Ltd.
West India and Panama Telegraph Co., Ltd. [now Cable and Wireless (West Indies), Ltd.].
Cuba Submarine Telegraph Co., Ltd.
Pacific Cable Board's Cables.
The West Indian Cable and Wireless System worked by the Pacific Cable Board.
The Imperial Atlantic Cables.
Post Office Beam Services.

The Company has controlling interests in:—
Indian Radio and Cable Communications Co., Ltd.
Marconi Radio Telegraph Co. of Egypt.
Overseas Communications of South Africa, Ltd.
Companhia Portuguesa Radio Marconi.
Peruvian Telephone Co.
Guayaquil Telephone Co.
as well as interests in
Amalgamated Wireless (Australasia), Ltd.,
and a number of foreign wireless companies.

APPENDIX 2

ROUTES OF CABLE AND WIRELESS SERVICES FORMING THE TELEGRAPH COMMUNICATION SYSTEM OF THE BRITISH EMPIRE

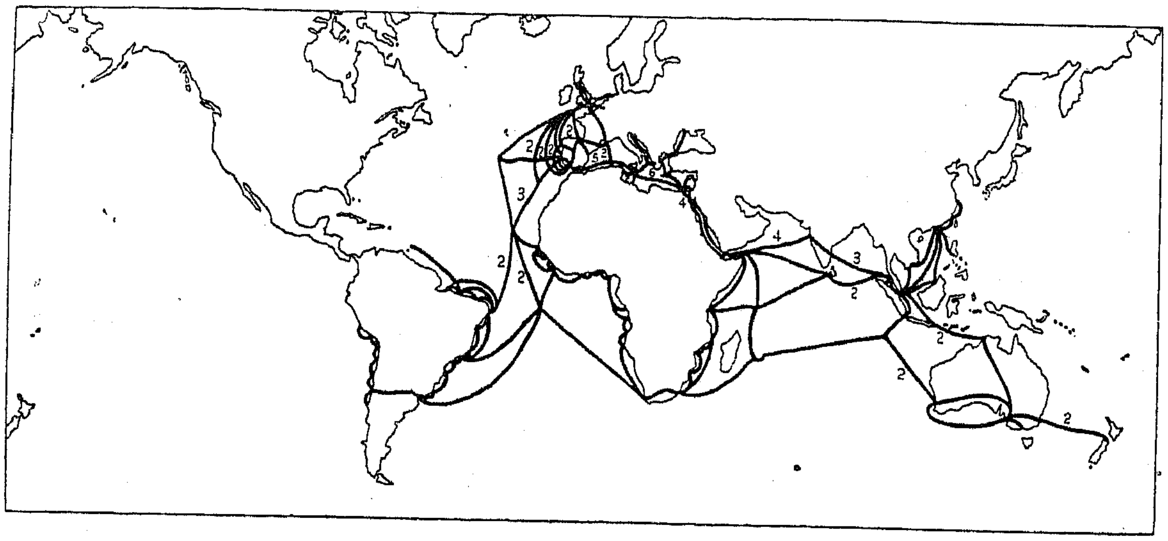

Fig. 37.—Eastern and associated Companies' systems prior to the merger.

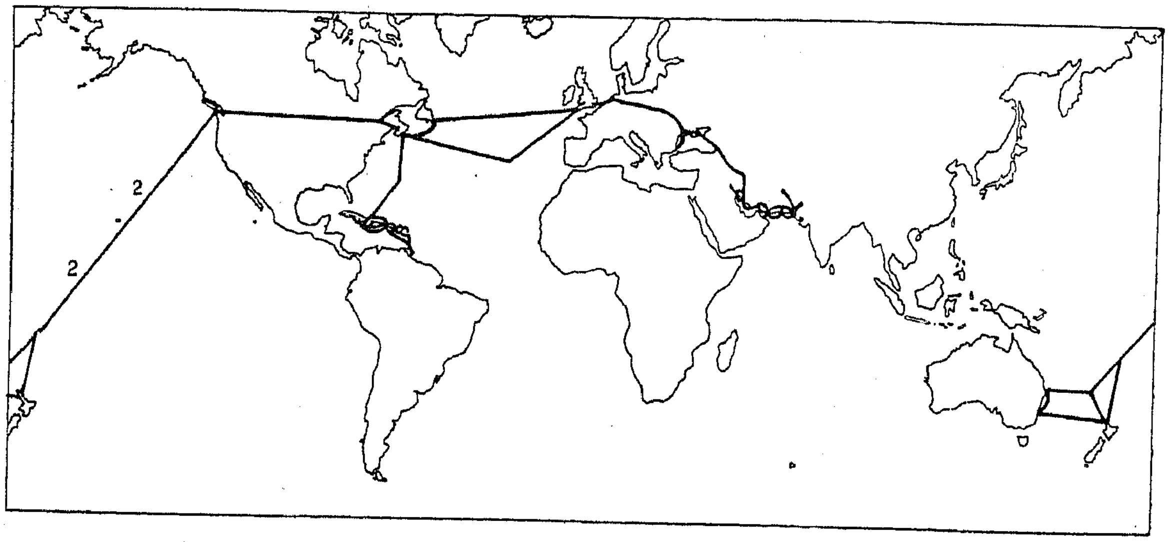

Fig. 38.—Other cable and landline systems incorporated in the merger.

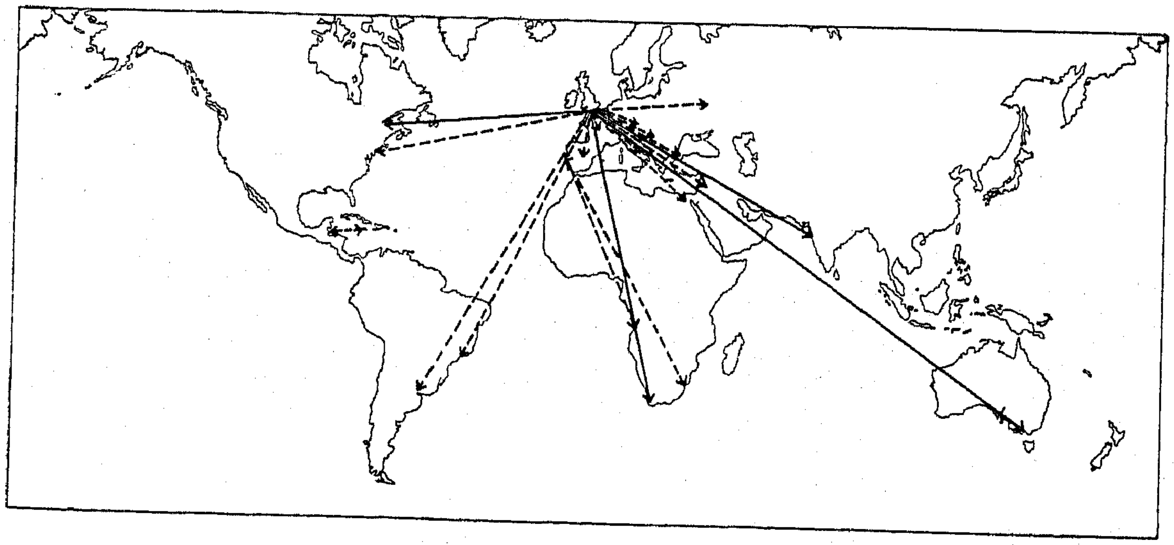

Fig. 39.—Wireless services prior to the merger.

——— G.P.O. beam services.
- - - - Services of Marconi Co.

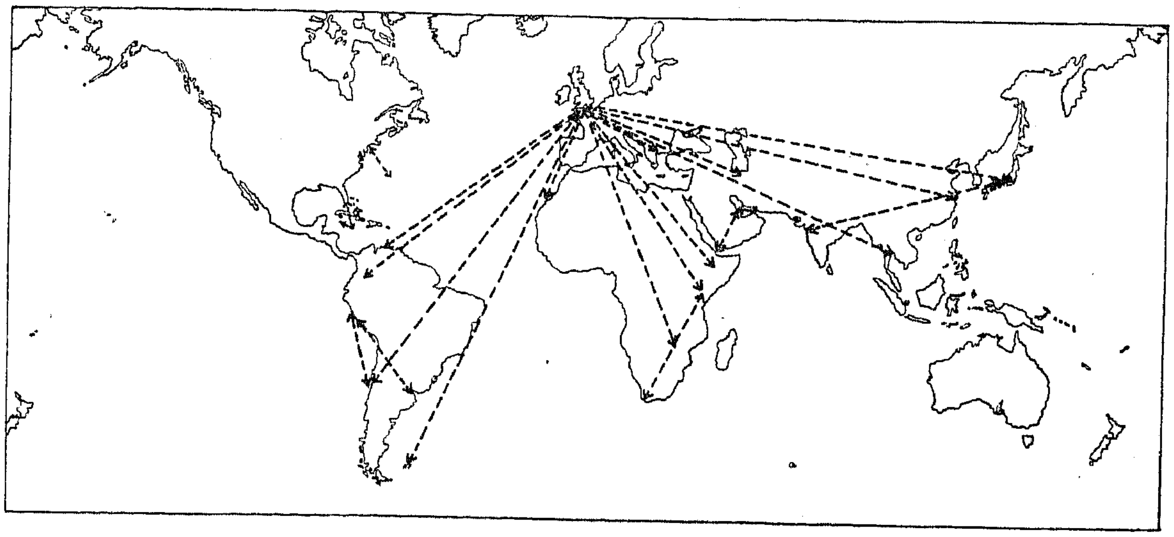

Fig. 40.—Wireless services opened since the merger.

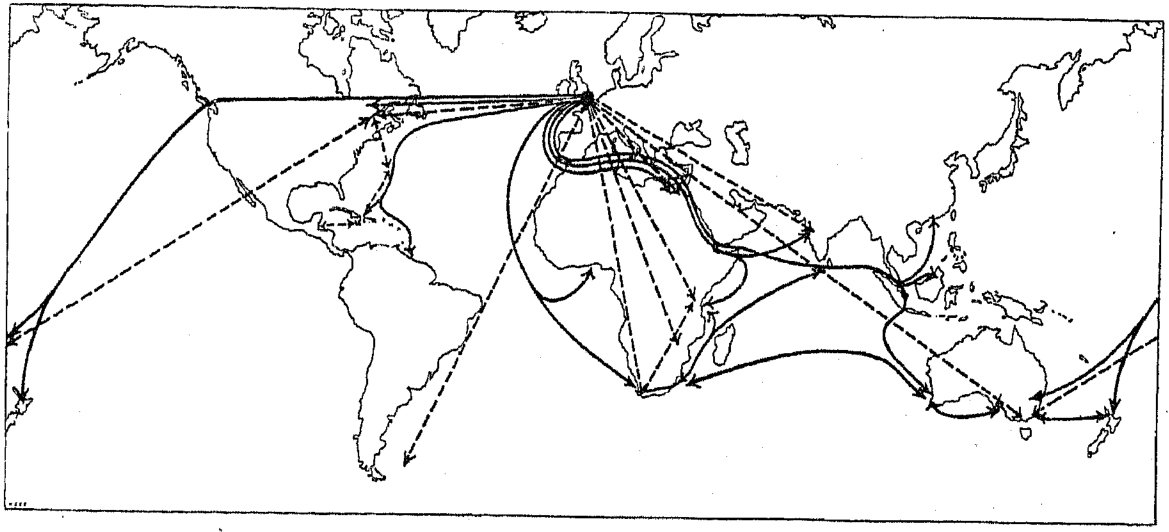

Fig. 41.—Routes of main inter-Empire traffic.

——— Cable and landline.
- - - - Wireless.

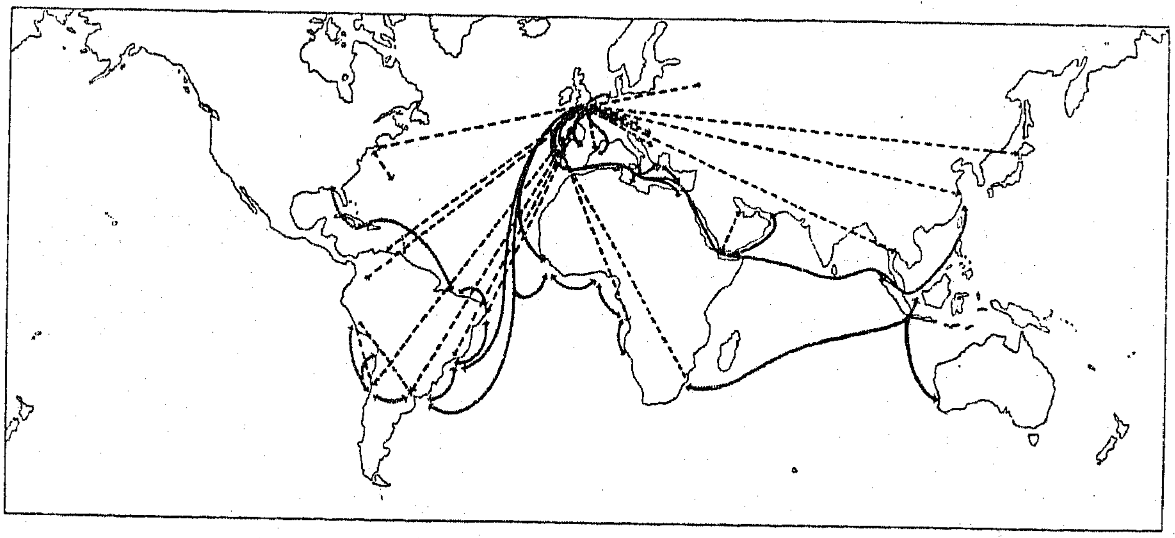

Fig. 42.—Routes of main Empire-foreign traffic.

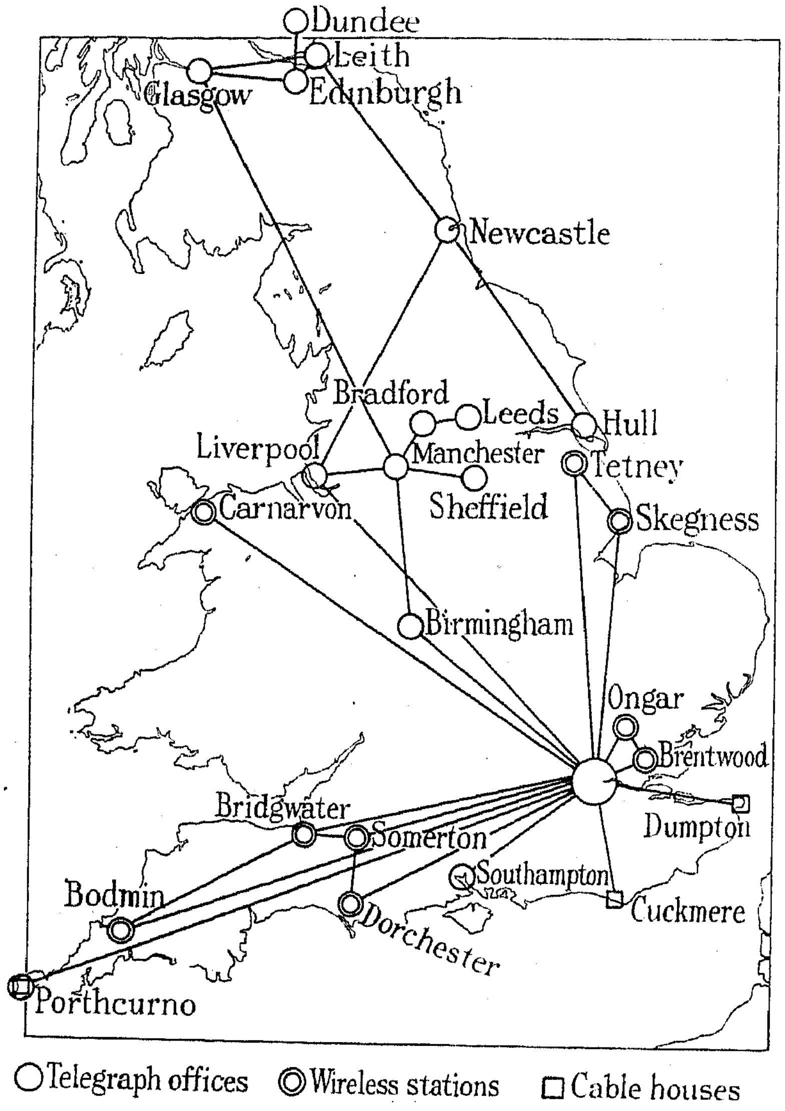

Fig. 43.—Landline system in the British Isles.

DISCUSSION BEFORE THE INSTITUTION, 15TH DECEMBER, 1938

Sir George Lee: The apparatus used in submarine-cable telegraphy has an extraordinarily high degree of precision as regards finish and manufacture and in the accuracy of the balances, great advances having taken place in the last decade.

I have been very interested in the author's description of the division of traffic between the cable and the wireless services. It is quite clear that the combination makes for economic utilization of the two services, and they are now complementary to each other instead of being competitive. I should be interested to know what happens when one terminal or the cable associated with it goes out of action owing to a fault. When the terminal goes back into action, how is the chain picked up again?

It is mentioned in the paper that the capacitance magnifier has the property of acting as a filter; low-pass filters would carry out that part of the operation much more simply and certainly, but the capacitance magnifier seems to have the advantage of isolating the cable from the amplifiers.

The author's description of the way synchronization is handled is very interesting; I should like to ask whether the use of crystal oscillators has been considered for this purpose. The degree of constancy of crystal oscillators is most remarkable; they keep constant to a fraction of a second over long periods of time.

Perhaps the author would say whether trailing electrodes, as we call them, have been used for tracing faults in submarine cables on his system. They are applicable mainly to comparatively shallow waters; we find them very useful in the North Sea, where cables become sanded-over and the pick-up gear cannot get hold of them. The method is to pass a low-frequency alternating current along the cable, and to trail the electrodes some distance away from the ship by a paravane arrangement. The alternating current can be detected by means of amplifiers and telephones on the ship until it has passed the fault.

I notice that the word " baud " is used in the paper as a time-interval, and I should like to argue in favour of observing international agreements on this subject, which define " baud " as a speed.

We have had the same sort of experience as the author in regard to armoured wires. I received a report a few weeks ago on the difference in the armoured wires of two cables laid side by side off the Shetlands. One was laid in 1885 and the other in 1902, but the condition of the armouring on the 1885 cable is at present far better than of that on the 1902. Similar effects are noticed on a single cable. I was present at the picking-up of a 60-year-old cable in the Irish Sea. There were hundreds of yards of beautiful galvanized armouring, and then suddenly a patch from which the wires had nearly disappeared. It is suggested in the paper that the effect is due to bacteriological action, which is an interesting possibility.

I am interested in the author's description of the time-delay of echoes which apparently go round the world two or three times. We do not know the speed at which wireless waves travel, nor the paths which they traverse. Does the author notice any deviation of the waves from a straight-line path between the transmitter and the receiver? On the long-distance services, e.g. between England and Australia, any very slight deviation would be of the greatest importance, because the waves might miss the receiving station altogether. On shorter distances there has been evidence of deviations of wireless waves. The existence of such deviations is important from the point of view of the design of the beam aerials. If the waves are liable to wander it is no use employing a very narrow beam.

The author indicates that 1937 is likely to have been the peak year in regard to solar activity. In general, the disturbances we have had in 1938 have been greater than in 1937, but there is a tendency for the optimum wavelengths to become longer. In October, 1938, there was a very large sunspot, but it caused relatively little disturbance to communication.

Mr. A. Davidson: The system with which I was associated a good many years ago decided to adhere throughout to the three-positional cable code, even on landlines. One of these crossed the tropical belt of South Mexico and the other the southern part of South America. We had all the usual trouble with landlines, but we managed to maintain the cable code in operation by putting on enough power. We used at one time as much as 220 volts positive and negative.

We had trouble with what we called " low insulation " of our cables in tropical waters. These sections became troublesome when inserted in long chains, and in order to maintain sufficiently good duplex working to keep these cables in the long chains we adopted something similar to the arrangement shown in Fig. 5. We had no idea then of the beneficial effect of the extra apices, as disclosed in Figs. 9(*a*), 9(*b*), 9(*c*), 9(*e*), and 9(*g*). A concentric-type core was laid on the shore end of the Miami–Havana cables, and I have wondered since whether this type of shore end could be used to advantage instead of the 3-core type shown in Fig. 5.

It was my lot at one time to have a good deal to do with repairs, and we found that the earth-current disturbance always occurred in the western section of our Atlantic cables. We attributed this to the fact that this section of the cables was much nearer to the north magnetic pole than the eastern section, and therefore was more affected by fluctuations in the earth's magnetism.

I see that the voltage used on the cable referred to in Fig. 16 is 70 volts. We used up to 100 volts, and it did not seem to do the cables any harm.

Will the author state whether continuously-loaded cables laid down 10 years or more ago maintain their properties?

Mr. F. W. Phillips: On looking back over the past 25 years even the layman must marvel at the great strides which have been made in the technical sphere. Speeds of transmission have improved, systems of automatic retransmission have been developed, wireless ranges have been increased, and more circuits than formerly can now be obtained with a given number of lines.

When I entered the Overseas Telegraph Department of the Post Office 25 years ago the great struggle between cables and wireless was beginning. One of the first documents I read when I took up my new task was a forecast by a Government official as to what would be the outcome of the struggle. He set out the advantages and disadvantages of cables and of wireless—the secrecy of cables, the ability of wireless to reach innumerable points, the difficulties of interference and shortage of wavelengths with wireless—and pointed out that from the point of view of cost cables were preferable for short distances and wireless for long. He came to the conclusion that there was a wide field for both, that they would each survive and would each find their own level. His forecast has proved fairly accurate. It would be interesting to know the author's view as to what will ultimately happen.

Three years ago I was a member of the Committee which went to the United States to study the position there in regard to television. We had a long talk with the president of the Radio Corporation of America, who held the view that the day would come when television would supersede all forms of telegraphy, wireless, and cables.

It is gratifying to recall that the Empire telegraph communication rates were substantially reduced in the spring of this year. We all hope that the reductions will result in a great increase in traffic.

Mr. T. E. Herbert: I am pleased to learn that the use of the telephone for transmitting messages to the cable companies is increasing. A similar tendency has been observed in the growth of phonogram traffic in the Post Office; but does not the author think that the ultimate and best solution of the " handing-over " problem will be the use of the Telex services?

Dealing with the author's remarks in Section (5), page **641**, may I suggest that there is no controversy whatever as to the greater speed of the 3-element as compared with the ordinary 5-unit code. The number of errors over cables is exceedingly small, and necessarily so, because of the importance and cost of the messages; but since the 5-unit code is actually in commercial operation over certain cable circuits it would appear that the error liability cannot be appreciably higher than that of the 3-unit code.

I should like to know whether when a long cable is required to be laid the author would not employ a coaxial or concentric cable. If so, he would then have to use the 5-unit code.

Has any progress been made towards finding a synthetic insulating material? Styrex compounds seem to promise good results, but at the moment their mechanical properties are unsatisfactory. However, research workers are now relating very accurately the molecular structure of a substance to its physical properties, and therefore it would seem that the position is not without some hope.

If the carrier system were introduced it would enable the simple and long-developed 5-unit printer to be used. For cable code we have seen a beautiful solution, in the shape of the Warburton printer, of a problem which has existed for many years. There is another solution to that problem, which is artificially to add to the unequal units of the 3-element code the required number of units to make each letter into five units, by using a complicated bank of relays; in this way the ordinary multiplex printer can be used.

The next point I should like to raise is in regard to the earth-current trouble. In all ordinary circumstances the devices of Mr. Wood and Mr. Higgitt take care of the earth current quite well, but when very serious earth-current disturbances occur, e.g. during a great storm, these corrective arrangements seem likely to prove inadequate. If a severe storm lasted for a considerable time would the author make some special arrangement to revert to plain double block and so prevent direct earth current going through, or would the complications involved be too serious?

The next development of the system which I should like to see is the linking of the perforator and the transmitter, not by perforated tape but by some sort of storage device. Using the 5-unit code, the length of tape for a given number of words is about three or four times the length for the corresponding cable code. The problem involved with the unequal-letter code is certainly a very difficult one, but I think that a solution will ultimately be found.

I was privileged to see the results of a large number of fault-localization tests at Porthcurno, and was struck by the extraordinary accuracy with which the positions were determined.

The next point I should like to mention is the duplex balance. One particular cable with a conductor resistance of 1 ohm per mile proved impossible to duplex, and some of the leading mathematicians of the day were called in to find a solution of the problem but failed to do so. Ultimately, the cable was balanced by cable officers using trial-and-error methods. The balancing of a new cable seems to be a matter requiring extraordinary patience allied with vast experience.

I have recently had an opportunity of inspecting parts of the author's system, and have been particularly struck by two things. The first is the extraordinary flexibility of the channelling methods in use, by which any emergency can be catered for and traffic diverted. The second is the beautiful mechanical design of the apparatus, the chief credit for which may be fairly given to the author.

Mr. H. Kingsbury: Over a long period the average interval between trawler interruptions on certain Western Union cables was of the order of 13 months; the solution of the problem therefore assumed major importance in the case of the Atlantic-cable interests. I have been closely associated with the experimental work in connection with that Company's method of ploughing, and I can say with confidence that a considerable degree of success is expected. Operations have already been accomplished which are successful by all tests except that of time. The author is apprehensive on two points, but I believe each of these is a matter of experience in details of the technique developed rather than of fundamental difficulty. As regards crossings, sufficiently fine control of the operations may be anticipated to enable two cables to be ploughed-in at different depths without any risk of the first (or lower) one suffering damage while the second is being laid. As regards light types of cable, reasonably shallow depths present no difficulty and in deeper water (300 to 500 fathoms) the accurate regulation required in the laying tension will probably soon be realized. The heavy type selected for the pioneer operations on working circuits gave a margin of safety which it was natural to seek in the circumstances.

The use of tough rubber as an external jacket offers considerable promise as a protection against chafe in shallow waters and on shore ends. Experimental work is in progress in this direction.

The author's emphatic defence of the 3-position code and the development by his company of an entirely new and apparently very promising printer indicates a strong faith in his arguments against equal-letter double-current codes. Taking the long view it must, however, be recognized that the relative simplicity and economy of 5-unit printers, the tendency towards through switching systems, and the possibility of carrier methods even on ocean cables, may ultimately displace the methods at present quite rightly favoured by the author. Similarly, his advocacy of the moving coil as a mechanical filter in the capacitance magnifier is in line with the successful survival of the Heurtley magnifier on other companies' systems. Nevertheless, recent experience with valve amplifiers has at length shown that properties equivalent to those to which he refers can be attained, combined with the associated advantages of stability and simplicity of maintenance for which thermionic apparatus is now so well known.

Mr. H. H. Harrison: The author mentions as one of the reasons for the non-adoption of the 5-unit code on difficult circuits the fact that (i) it cannot be read at intermediate points without being translated, and (ii) an error is not recognizable. This difficulty can, however, be very easily overcome by adopting a receiver at intermediate points, either a re-perforator or a multi-pin recorder, and distinguishing between spacing and marking signals. Referring to Fig. A, the marking and spacing signals are produced in two separate vertical lines and their sum should always be 5. Thus by scanning the tape an error is at once apparent, as the addition or omission of signal elements will cause the total (marking + spacing) to exceed or be below the number 5. To avoid the necessity of phasing the perforator, the marking holes may be rectangular while the spacing holes remain circular.

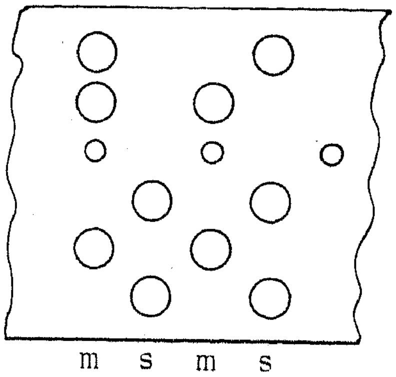

Fig. A

I am surprised at the author's statement that the Verdan system cannot deal with both fades and atmospherics. As a matter of fact, one of the first to tackle the problem of dealing simultaneously with the two forms of disturbance on radio circuits was Verdan himself.

His method, which he described in 1933, relies on two receiving relays, and signals are only passed on to the printer if one of the relays operates. The effect of fades or atmospherics is to operate or not-operate both relays, in which case they have no effect on the printer. It is probable that the method which uses a spacing and a marking wave gives more satisfactory results.

The direct printing of unequal-letter codes by employing a 5-unit-code printer and using filler relays to bring every letter signal up to 5 units in length has, I believe, been adopted by the Commercial Cable Co. This method seems to me to be an unnecessary complication and is, moreover, not required since with the ingenious chain-relay distributor designed by that Company, direct printing is readily attainable without the auxiliary circuits which their method entails. The Warburton printer is a much more practicable solution of the direct printing problem. As far as I know, it is the only printer with a mechanical distributor which, without any modification in principle but merely a rearrangement of parts, will deal with either an unequal alphabet such as the cable code or the landline Morse Code, or an equal-letter alphabet code such as the 5-unit, operated either continuously from a transmitter at the sending end or by start-stop methods.

Mr. W. F. Bevis: Referring to Mr. Herbert's question as to whether the author's corrective arrangements are likely to fail when earth currents are very severe, it is of course well known that the impulse method of working eliminates the earth current from the receiving network, and such an arrangement would probably be more satisfactory.

One such method would be a straight amplifier receiver with a transformer input and working on the impulse principle. A low-pass filter cutting off at approximately the third harmonic of the fundamental signalling frequency would eliminate the high-frequency components of the out-of-balance disturbance.

This arrangement would remove the earth currents from the receiver, and an earth-current corrector would therefore be unnecessary. Also, all sensitive moving-coil apparatus would be eliminated, and an all-round reduction in maintenance would follow. I am aware that the introduction of an amplifier leads to difficulties in balancing, but I think it possible that the use of a transformer method would greatly reduce them.

Mr. J. F. Brock: I should like to inform Mr. Bevis that valve amplifiers such as he mentioned are at present operating on many of the Atlantic cables. Their response curve is very similar to that of the moving-coil magnifier-relay system. They are more stable than the moving-coil systems as regards signal shape, more robust, and permit rapid readjustment to meet changes of speed or signal code.

None of the previous speakers has referred to the advantages of the 5-unit code for channelling purposes, especially for speeds of, say, 2 000 letters per minute. On one of the Atlantic cable circuits operating 5-unit code at 2 400 letters per minute there are 8 channels operated at 300 letters per minute. In common with other 2-element codes, the 5-unit code can be transmitted at such speed that almost complete attenuation of the single unit impulses takes place—the attenuated impulses being "filled in" at the receiving end by a properly designed regenerative repeater. The output of the cable can thus be nearly doubled. This method of transmission is not applicable to recorder code. Another advantage of the 5-unit code is that storage transmitters can be used.

The system of Empire communications which the author describes seems to be very efficient but is developing on rather old-fashioned lines with improvements in instruments. It is not necessarily the most modern system in all respects.

Mr. R. A. Goodman (*communicated*): Experience elsewhere in the use of valve amplifiers for reception on submarine cables is hardly in agreement with the author's claim that moving-coil receiving instruments or "magnifiers" possess superior characteristics. The "filter" action of a suspended coil can be simulated, and even improved upon, by electrical means; valve amplifiers incorporating signal-shaping networks are in common use on both long and short cables, and have the advantages of greater ruggedness, ease of adjustment, and simplicity of maintenance.

Working with unshunted signalling condensers, with the object of discriminating against earth currents, is more easily maintained with valve amplifiers. Local correction, by feed-back from the output of the amplifier into, say, the grid circuit of the last stage, can be nicely adjusted and is very stable. Alternatively, the lower-frequency components of the signals of a 2-positional code may be rejected in the coupling networks of the amplifier (so-called impulse signalling), which are then very insensitive to earth currents and yet are of simpler construction than those which must admit signal components of less than the fundamental frequency.

The description of the automatic bias corrector brings to mind once again the difference of opinion among telegraph engineers concerning the relative merits of concentrating, on the one hand, upon the exclusion of currents which would cause bias, and on the other, upon making less discrimination and providing corrector devices for removing bias after it has occurred.

It is suggested that future developments in duplex balancing of cables will involve the incorporation of inductance, as well as resistance and capacitance, in artificial lines, at least in the part simulating the head-end of the cable. In the majority of cases, however, it seems probable that extraneous interference will limit the working speed before the possibilities of the resistance/capacitance artificial line have been exhausted, and that in the never-ceasing search for higher working speeds the development of the technique of interference-suppression, as applied to submarine telegraph cables, will next demand attention, as a direct consequence of using the higher gain possible in valve amplifiers.

One would like to ask the author his views on the automatic control of temperature, at a level above the maximum dew-point, in artificial-line rooms. At some Canadian cable stations, temperature control has been found essential.

A brief description of the means whereby the clocks at the various stations are checked would be appreciated. It is assumed that temperature-control of the clocks is regarded as an unnecessary refinement; one would be interested to know the maximum error tolerated in a working clock.

It would appear that the continued importance of telegraphs in the commercial communications field of the future will depend to an increasing extent upon closer coupling of national with international systems and customer with customer. Developments must inevitably occur at a slower rate than that at which trunk working has advanced in telephony, but there is justification for the view that preparation should be made for the gradual trend. The use of 5-unit code on long submarine cables, already well established, makes possible such ready connection of cable circuits to existing inland feeders that further conversions of non-loaded cables from 3-positional cable code to 5-unit code seem inevitable. The comparatively high speeds of which loaded cables are capable cannot be utilized efficiently by any other method than that of channelling by line-time division with 5-unit signalling and automatic printing. Two-positional cable code, with the necessary doubling of the fundamental frequency of signalling and consequent reduction of message capacity below that obtainable from 5-unit code, is, when considered from a general point of view, an illustration of the limitations of the present 3-positional code. One does not wish to minimize the disadvantages of the equal-length code, but one feels that since national systems are firmly wedded to start-stop telegraphy each international system must eventually face and overcome for itself such technical difficulties as are associated with long-distance 5-unit working. The probability seems very small that some method of translating from the one code to the other in the terminal apparatus will be a satisfactory alternative.

Dr. K. L. Jensen (*communicated*): In his paper the author, naturally, gives prominence to the improvements that have been made in working cable code, but it will, perhaps, be admitted that improvements have also been made in working Morse Code and, as an instance, it may be of interest that the Great Northern Telegraph Co. have achieved with the latter code a speed of 145 words per min. (121 bauds) on a cable with a *CR* value of 0·7 ohm-farad with the most up-to-date Gulstad equipment, including amplifiers and a receiving relay of the three-positional type. With older equipment (amplifiers and Gulstad relay) a speed of 80 w.p.m. (67 bauds) has been achieved on a cable with a *CR* value of about 1·2. Both these speeds were maintained with normal duplex working.

For working long and difficult landlines and linking these with cables, perhaps no code is better suited than the Morse Code. A 3-positional code would, in this case, be out of the question, and the Morse Code is superior to other double-current codes because of the ease with which it is possible to read the signals at intermediate repeater stations, thereby facilitating the checking-up of errors and, perhaps, still more important, the checking of the adjustment of the repeater with a view to avoiding errors. In this connection it may be of interest to record that the Great Northern Telegraph Co. is operating two 10 000-km. open lines through Russia and Siberia with 760-nautical-mile cables at one end with respectively 19 and 20 repeaters at 60 w.p.m. (50 bauds) duplex. At suitable, selected repeater stations, regenerators of a simple and robust type are added to the otherwise simple repeater equipment required for morse signalling. Reception at the terminal stations is by automatic reperforators.

It will, no doubt, be agreed that in its particular field as cited above the Morse Code scores also when regard is paid to the questions of cheapness of apparatus, easy maintenance, and simple technical supervision, for which a fairly elementary training suffices.

[The author's reply to this discussion will be found on page 668.]

NORTH MIDLAND CENTRE, AT LEEDS, 28TH FEBRUARY, 1939

Mr. W. F. Smith: Referring first to Fig. 1, I notice that the engineer-in-chief maintains contact with other branches such as Accounts, Contracts, Stores, and so on. Is it to be understood that these branches are complete in themselves, and that the engineer-in-chief has no direct control over them? Referring specifically to the Staff Branch and the Contracts Branch, these seem to be so intimately bound up with engineering functions that direct control by the engineer-in-chief would appear essential. The staff manager is responsible for the recruitment of engineering personnel, and this must call for a very wide engineering knowledge of the functions performed. It is not easy to see how the staff manager is able, without a direct engineering function as well, to keep in touch with the engineering developments in order that he may be in a position to select suitable candidates.

It is mentioned that the matriculation standard is required of new entrants, who are then given a 2 years' course—mainly theory. I should like to know whether that course is a full-time one, carried out by the company, or whether it is carried out by the ordinary educational authorities and practical training given by the company at a later stage? It would be interesting to know what is expected of those recruits at the end of 2 years. Are they expected to shoulder responsibility, or do they work as assistants to skilled engineers? As far as I can see their only duties will be maintenance work and adjustments, localization of faults, and perhaps installation work of a minor character. It would seem that little opportunity exists to obtain the highly technical skill which they will find necessary if they are to take over control of the stations, particularly of those which are very isolated.

I am not clear as to the method adopted in fixing the dot and dash selection points in actual practice. With the double-current cable code the dot selection point is three-quarters of the way along the signal element, and a dash one-quarter of the signal element. I have not been able to discover the length of a signal element, but the tolerance between dot and dash signal elements appears small and may give rise to frequent errors.

In connection with the automatic calling and switching device, it is mentioned that a dot following a series of dashes or a dash following a series of dots resets the apparatus, so that any signal which is composed of dots and dashes results in the apparatus being set to zero. It would appear, therefore, that the special calling codes must consist of a series of dots or a series of dashes greater than 5 in number to distinguish the call from any signal used for ordinary signalling in the international code. I should be glad to know what are the actual signals, or types of signal, which are used for this calling device.

In the section on "Protection of Cables" a method of ploughing-in cables is mentioned. This presumably is confined to the comparatively shallow shore ends. There will be a point beyond which it is uneconomic to plough-in, and at this point there would seem to be grave danger of damage due to the swinging of the open cable in the tide. Is any special method employed to anchor the cable in the plough trench?

Mr. R. Towers: On page 652 it is stated that "The main circuits, both transmitting and receiving, retain the Franklin vertical beam aerial in a modern form; no other form of aerial has proved to be equally effective, having regard not only to signal fields but also to signal/noise ratio and to the reduction of echo." I should like to ask whether that statement is based on any quantitative data and whether any comparison has been made between the vertical type of array and horizontal types. Experience in the Post Office has shown that very good results are achieved with the horizontal type of array. My personal experience has been that if the horizontal array is properly lined-up it gives results comparable with those provided by the vertical type.

The statement that the type of array referred to improves the signal strength and also reduces echo appears rather contradictory. The description suggests a high-gain array of a highly directive type, with a large front-to-back ratio. I should think the high gain would tend to increase the effect of echo. If the author meant the reduction of the effect of signals arriving by the backward route I should agree.

I observe that the automatic gain control is operated from the low-frequency output of the audio-frequency amplifier. I should like to ask whether there is any special reason for this, and why the gain control is not operated at the intermediate frequency. What is the time-constant of the circuit, and has the author envisaged the use of a variable time-constant to provide for different conditions of fading?

As regards the keyed tone-sender, I should be interested to know the frequency of the tone, and what is the maximum possible speed. A system of similar type was in use in the early days of the beam on the landlines in India, and at times of heavy rain—though we had perfect radio conditions—the landline limited the maximum speed of the circuit. I should like to know whether this difficulty is still being experienced.

On the Australian beam a single wavelength but two alternative directions of transmission were used. There were large gaps in the reception which varied with the solar cycle. Have any attempts been made to obtain an alternative to the 25-metre wavelength, to bridge over those gaps?

Mr. P. R. Couch: The particular section of this paper which captures my interest is that referring to the laying and maintenance of submarine telegraph cables. It is known that corrosion of the cable armouring occurs to a large degree in warm waters, and this, coupled with the fact that the movement of the water at great depths is negligible (a statement which is borne out by the undisturbed condition of recovered fabric), leads one to the assumption that the majority of cable faults are confined to the neighbourhood of the shore ends. The paper indicates that in the main the cable faults are due to corrosion and to the operation of trawlers. Emphasis is here laid on the former cause. In stressing this point, does the author imply that as a rule the corrosion of the armouring results from the chafing of the cables in comparatively shallow waters? Also, has he knowledge of any cases where corrosion has taken place in deep waters but where the cable failure is attributed to the insulating material rupturing on account of the excessive pressure?

The author refers to various tests employed for the purpose of fault localization, and indicates that the overlap test is favoured. Does this mean that this test is regarded as the fundamental one in general practice, the other methods being resorted to for check purposes if necessary?

One test which has been successfully used by the Post Office in the case of earth faults on submarine cables is the towed-electrode method, and it would be interesting if the author would say whether this scheme is used, within its accepted scope, by the administration.

Another test which is used to advantage on telephone cables is the impedance/frequency test, and perhaps the author would indicate his experience in the use of this method. I appreciate that both of these methods have limited application in view of the inordinate length of the cables in question, but if my earlier assumption, that the faults occur in the main at the shore ends, is correct, then I feel that they may be profitably applied in a large number of cases.

Mr. C. O. Horn: I should be interested to know why the arrangement shown in Fig. 5 has both a short sea earth and a long sea earth at the shore end. Does "A. L. balancing sea earth" mean an artificial line, and does it simply serve its purpose in balancing the appropriate portion of the electrical bridge?

Like Mr. Smith, I am interested in the Western Union ploughing method. The author says that one of the difficulties relates to crossings (I presume that "cable crossings" is intended). I am surprised that the cables do cross each other.

Referring to Fig. 33, it is interesting to note that the value giving the usable portion of the day is practically identical with the sunspot number. If there is any direct relationship between the sunspot number and the usable portion of the day, it is quite contrary to what I understood was found in practice. It is a fact, of course, that the curve shown in Fig. 33 extends over the last 8 years, and I should like to know how much of the increased usable period is due to improved transmission or reception and greater knowledge of the subject.

I am not familiar with the Murray reed, but I presume it is a metallic one. If this is so, I should like to know whether there is any necessity to correct for temperature or other variations. Is the reed made of elinvar, or something of that nature?

Mr. T. F. Barlow: According to various books on the working of the early Atlantic cables, the first Atlantic cable ever laid was worked by means of huge induction coils generating tremendous voltages. These were fitted by the electrician Whitehouse. As might be expected, after a short time the cable insulation was broken down and the cables ceased working. Lord Kelvin (then Prof. William Thomson) came to the rescue and succeeded in getting the directors of the cable company to use his pattern of reflecting galvanometer. This made use of a minute current at a correspondingly small voltage, and in some cases the cable was isolated from the apparatus by a condenser connected in series. The rate of transmission, however, was very slow. At a later date Lord Kelvin introduced his siphon recorder, and this was used in conjunction with a form of automatic punched-paper-tape transmitter and curbing currents. I am surprised to learn from the author that the voltage used in working submarine cables to-day is of the order of hundreds of volts. From what I have just said it would seem that 200 volts is a dangerous voltage to apply to a long submarine cable.

THE AUTHOR'S REPLY TO THE DISCUSSIONS

Mr. K. L. Wood (*in reply*): Replying to Sir George Lee's question of what happens when one terminal in a cable regenerator chain goes out of action, the answer is that any station on the chain can immediately become the terminal. The regenerator system used on the British cable system differs from most synchronous telegraph systems in that the uncorrected speeds of the apparatus at all stations in a chain aim at being the same; corrections are automatically applied either to advance or to retard the phase, as required, in order to maintain exact synchronism. This enables the chain to be broken up into any number of sections without loss of synchronism and any station can transmit, since a tape-transmitter forms part of each regenerating instrument. It takes only a matter of seconds to restore synchronism throughout the chain when it is extended to the original or to a new terminal.

As regards crystal oscillators for speed-control purposes, we could not expect improved working, and to change over would involve very heavy expenditure. Considerable complication is involved in obtaining from crystal oscillators low frequencies suitable for a cable regenerator.

We have successfully used trailed electrodes in our cable ships; but a large proportion of our repair work is done in water too deep to enable them to be used. I appreciate the useful pioneer work carried out by the General Post Office on trailed electrodes, the results of which were freely disclosed in the *Post Office Engineers' Journal.*

In regard to the path and velocity of wireless waves, from the earliest days of short-wave commercial circuits there has been evidence of communication taking place at certain times over paths other than those in or near the great-circle plane. In such circumstances the energy received on normally-directed aerials is necessarily weak, and reception is materially improved by the use of misdirected aerials. In the absence of a steerable aerial there is thus a limit to the degree of directivity which may be usefully employed. With the echo signals on the African and Indian beam circuits referred to in the paper, however, very high signal levels were encountered, which, together with the fact that in Fig. 35 the commencement of each successive pair is equally delayed, and that in Fig. 36 the ratio of the two delays is sensibly equal to the ratio of assumed paths, is strong evidence in support of the belief that these rays were propagated at the velocity of light.

I confirm that 1937 is likely to have been a peak year of solar activity. The final sunspot index figure for 1938 [see Fig. 33(*a*)] is not yet available, but preliminary Greenwich Observatory figures indicate that 1938 will be below 1937, in spite of abnormally high activity during some particular months in the second half of 1938. Our observations show that optimum wavelengths have lengthened in phase with this reduced activity. If the greater disturbances experienced by the General Post Office in 1938 are to be taken as being magnetic disturbances, this is understandable, since magnetic activity, with its associated disturbing effects, appears to be still increasing. This tendency for magnetic activity to lag about 2 years behind solar activity has been noticeable in the last three 11-year cycles.

In reply to Mr. Davidson, I can say that since they were laid there has been no appreciable change in the properties of the continuously-loaded cables owned by the British companies. They are, however, all simplex cables, so that very slight changes of inductance would probably pass unnoticed.

Mr. Phillips asks for my view on what will happen with regard to the ultimate relationship of cable and wireless communication. I hesitate to prophesy, but I do think that cables will always be retained on the main traffic routes, whilst wireless will continue to serve points lying off these routes where the volume of traffic is insufficient to justify the expense of cables. On the other hand, long-distance wireless services will generally be retained and probably extended; this view would be modified if cables could be cheapened by (*a*) a less-expensive insulator of low loss, (*b*) the use of fewer sheathing wires, efficiently protected against corrosion. One factor tending to this use of fixed wireless services is the willingness of many Governments to run uneconomical direct wireless services in order to avoid handing messages over for transit through other countries.

Mr. Herbert asks if the best solution of the " handing over " problem will not be the Telex service. The use of the Telex will undoubtedly increase, but for handling " flash " traffic a skilled operator on a telephone is unexcelled. I am aware that the 5-unit code is in use over certain cable circuits, and in certain circumstances this is justifiable; but where sudden changes of set-up of cables are required, as in a large network, the use of a 2-position code which, as shown in the paper, becomes either a wholly or a partly 3-position code according to the speed, would result in a loss of efficiency and flexibility. Five-unit code *as it stands* is unsuitable for circuits working near their distortion limit, or on long overhead wires subject to disturbance. This opinion is based on statistics, which show that, whereas the working on cables is very clean and free from errors, the majority of undetectable errors passed to the public have occurred in messages handed over to us by other administrations using on their system 5-unit or 7-unit code upon long overhead landlines. Mr. Herbert also asks whether future long cables will be coaxial or concentric. The economical limit of length of the type of unloaded submarine cable known as coaxial is of the order of 100 miles. When the length is 1 000 miles or more, a loaded cable (if high speed is required) appears essential and the possibility of channelling by frequency discrimination becomes remote owing to intermodulation; time-division channelling, however, would not make the use of 5-unit code inevitable.

The progress in the development of synthetic insulating materials is being watched, but at the moment a satisfactory substitute for gutta-percha has not been proved.

Mr. Herbert asks what would be done if a severe magnetic storm lasted for a considerable time. Such storms happen rarely and do not last long. When the rate of earth-current variation is of the same order as the received signal-current variations, as it can be on a long cable during magnetic storms, unshunted condensers do not provide a means of eliminating the earth currents. It is always possible to change to siphon-recorder working and, with repetition as required, dispose of urgent messages. We do not consider that reversion to double-block working would give any better results than our present system, with which, in the severest storm, it is rare to have more than a limited succession of short stoppages of 2 or 3 minutes' duration; in fact, we think we have overcome earth-current stoppages as far as is humanly possible.

The linking of the operator and the transmitter by a storage device is not new, but it results in a loss of flexibility in a large station. Once a message has been recorded on a perforated tape by an operator, this tape can be used on any circuit, whether cable or wireless. In the case of a storage device the sending of a message is confined to one circuit worked by one operator; in the event of a desire to send this message on another circuit owing to a stoppage or a fade-out, it must be rehandled by an operator. Storage by perforated slip enables deferred messages to be dealt with efficiently as regards staff arrangements.

Mr. Harrison's suggestion that 5-unit code signals could be recorded with marking and spacing signals in separate vertical lines, so making mutilation evident, seems to have no practical advantage unless each character is sent twice, once to record the marks and once to record the spaces; if a character is sent only once and a mark element is mutilated into a space, there will still be a total of five recorded elements.

Mr. Harrison mentions the Verdan method of catering for both fades and extras, in which one relay is operated both by signals and atmospherics and another relay by atmospherics only; it does not work in practice owing to the differential effects of atmospherics and fading. It is similar to the old proposal of separating the atmospherics, subtracting them from the signals plus atmospherics, thus being left with signals only. Wave-change working seems the practical solution.

The remarks of Mr. Bevis are largely covered in my reply to Mr. Herbert. Mr. Bevis and other speakers refer to the use of valve amplifiers for cables, claiming for them such advantages as greater stability and reduction of maintenance. It is evident from Fig. 10, showing that the average stoppage per circuit is less than 1 minute per day, that the scope for improvement due to greater stability is negligible. As regards maintenance, it is our experience that the upkeep of the numerous batteries required for valve amplifiers is far in excess of that required in looking after coil magnifiers, and this is particularly so in the tropics. The speed of unloaded duplex cables is limited by the duplex balance and/or disturbances; valve amplifiers offer no advantages in respect of this limitation. In some cases we have reverted from valve amplifiers to coil instruments, to the relief of the staff who had to maintain the instruments, and certainly with no loss of stability. It is obvious that stability is far more important on a cable chain with 12 intermediate stations than it is between, say, London and New York with only two or three intermediate stations. The numerous cable circuits between London and New York no doubt have problems far different from those presented by the world-wide network of British cables; the suitably modified landline apparatus used on the former circuits has presumably proved satisfactory but would not provide a solution of the problems associated with the latter network, with its numerous feeding-points and often very severe climatic conditions.

Mr. Brock's statement that the output of a cable can be nearly doubled by filling in attenuated impulses at the receiving end is not correct if actual traffic-carrying capacity of a cable is considered. Cable code, Morse Code with inserted impulses, and 5-unit code with inserted impulses, have all been tried out in actual practice and the net result is that a cable working at its maximum speed will carry most traffic with maximum reliability when using cable code.

Mr. Goodman asks for my views on the automatic temperature control of artificial-line rooms. This is being adopted at a number of our branches but is not generally necessary; its justification depends on two factors, the local climatic conditions and the properties of the artificial lines. Modern types of the latter are, of course, substantially free from variations due to temperature. It is often necessary to take steps to avoid deposits of moisture in artificial-line rooms without, however, aiming at a very even temperature.

As regards the checking of clocks at the various stations, this is done by whatever means is most convenient. London's clocks are rated with Greenwich time signals, and any station on a chain working with London has the difference between its clock (or clocks) and the clock London is using to control the transmitter recorded by a cyclometer on the regenerator apparatus. A persistent movement of the cyclometer one or other way shows a correction to be desirable. The clocks can be kept without difficulty to within an error of about 1 sec. per day, although many times this error can be tolerated without loss of margin in the regenerator apparatus. Since the clocks have invar pendulums, no temperature control is required.

Mr. Goodman states that the message-carrying capacity of a cable is more when using 5-unit code than when using cable code. On unloaded cables I think experience shows that there is little difference. In cable code a standard word of 5 characters plus word-space (18 elements) is equal in length to 9 cycles of the highest frequency which must pass through the cable and be used at the receiving end. The 5-unit word of 5 characters plus word-space (30 elements) is equal in length to 10 cycles of the highest frequency required to be used at the receiving end (the higher frequency of 15 cycles being lost and being reinserted at the receiving end by a vibrating relay or other device working on the Gulstad principle). The 5-unit code, however, has the advantage of the double voltage-change from positive to negative and vice versa; this, on unloaded cables, substantially compensates for the higher frequency necessary to transmit 5-unit code, resulting in about the same traffic-carrying capacity but leaving certain disadvantages such as greater duplex balance troubles, etc., as mentioned in the paper. On loaded cables it much more than compensates, owing to the slower increase of attenuation with frequency.

Dr. Jensen shows what can be done with ordinary double-current morse working. The Morse Code has certain marked advantages for long landlines, particularly when there are numerous repeaters. It also gives good results on short cables, but on electrically long cables it has been shown by our experience to be decidedly inferior to cable code, since each word has a length of 12 cycles of the highest frequency which must be received. The effect of the double voltage-change on the duplex balance is also objectionable. Nevertheless, the Great Northern Telegraph Co. have developed morse working to a very high state of perfection.

In answer to Mr. Smith, there is close collaboration between the Engineer-in-Chief's department and other departments such as Contracts, Staff, and Instructional. Specifications are made out in the Engineer-in-Chief's department; inspection of new apparatus is also carried out by that department, but tenders, prices, comparisons, etc., are attended to by the Contracts department except in the case of very large purchases, where joint recommendations for acceptance are made to the management. In the same way the actual engagement of staff, and their passages and leave arrangements, etc., are attended to by the Staff Manager, but close contact is maintained with him and with the Chief of the Training College so that engineering requirements are met as regards the standard of technical knowledge, the maintenance of stations, and the provision of suitable staff for special work.

With regard to training, the 2-year course is a full-time course and is carried out entirely at the company's training college; it will be seen from the paper, however, that it is only given to those who have shown special practical ability in a previous course which includes telegraph operating, electrical theory, and workshop practice. I should like to make it clear that the 2-year course is not mainly theory, as suggested, but includes training " in the use of all the apparatus of which they are likely to have charge " and " the attainment of sufficient skill to manufacture and repair any component part of the mechanical apparatus. Proficiency in cable fault and break localization is also attained." At the end of 2 years these men go abroad as assistants to skilled engineers, and under these officers gradually become sufficiently experienced to take over control of stations after passing an examination in both engineering and administrative subjects.

Referring to Mr. Smith's query regarding double-current cable code, a signal element may be either a dot, a dash, or a space, and in both cable code and double-current cable code all three are of the same length. At 150 words per minute, 45 selections are made per second in cable code, but in double-current cable code there are 90—45 dot and 45 dash selections being made alternately. The practical means adopted of making these latter selections is to cause a synchronously-driven cam to operate a contact lever momentarily, the decision as to whether or not a dot (or a dash, as the case may be) is selected being determined by the position of the receiving relay (to mark or space) at the moment of contact. I agree that the time available appears to be very short, but I assure Mr. Smith that errors due to apparatus are extremely rare and that a good margin for distortion of the signal elements exists.

The switching signals in the call device do consist of signals composed of a number of dots and dashes in excess of five. Typical selective calls would be:—

Station A: " Dot dot dot dash dot dot dot dash dot dot dot dash dot dot dot dash ";
Station B: " Dot dot dot dot dash dot dot dash dot dot dot dot dash dot dot dash."

If these two stations, A and B, were on the same chain and the first selective call as above was sent, the call devices at both stations would advance equally for the first three dots; the fourth signal, being a dash, would return B's device to zero, but since a cam on the shaft of A's device short-circuits the dash magnet, A's shaft would not return to zero. If a suitable arrangement of the humps on the short-circuiting cam is adopted, station A's shaft will advance 12 steps while B's is continually returned to zero. At the 12th step another cam on A's shaft causes contacts to be made which can light a lamp and effect switching. It will be seen that a large number of calls can be set up by adopting various permutations for each station, using both dot and dash sides for calling, switching, etc., and that further progress beyond 12 dots or dashes may effect further operations such as paralleling of perforators.

Ploughing-in of cables has been effected in depths up to 350 fathoms; where the water is so shallow that wave or tidal motion is likely to cause strain or chafe, a very heavy type of cable is used.

Replying to Mr. Towers, the references to the Franklin type of aerial were intended to draw a comparison between the " broadside " and the " end-fed " arrays, and the retention of the Franklin aerial in a modified form resulted from the fact that experience has shown that no other form of aerial is as effective as the " broadside " array from the point of view of signal/noise ratio.

The statement regarding reduction of echo by the use of the Franklin aerial was not intended to refer to " forward " echo. The relative intensities of direct and echo signals in this case are substantially independent of the type of aerials employed, being essentially a function of the total path attenuation around the globe which the direct signal encounters subsequent to its initial reception at the distant receiving station.

In the case of " backward " echo, however, the ratio of direct to echo signal for any given ionosphere condition is dependent upon the front-to-back ratios of the transmitting and receiving aerials, and it is in this respect that the Franklin aerial has proved to be so effective. As part of the quantitative data obtained in this connection may be cited an analysis of the reception in South America of a number of European stations during 1937, a year when the solar conditions were particularly conducive to such effects; the amount of " backward " echo experienced on the London circuit where a Franklin aerial was used was negligible compared with that experienced in reception from the remaining European points where other types of aerial were employed.

The automatic gain control is operated from the audio-frequency amplifier, for convenience; a range of time-constants to meet the various types of fading is available, a value between 0·05 and 0·1 sec. being frequently used.

The frequencies of the tone-senders range from 360 cycles per sec. upwards, according to the characteristics of the underground cables employed. A 240-cycle spacing of the band-pass filters enables the channels to be satisfactorily worked at speeds up to 150 words per minute.

The use on the Australian circuit of wavelengths from 15 to 18 m., and from 32 to 37 m., has partially eliminated the gaps hitherto experienced on the 25-m. band.

In reply to Mr. Couch, corrosion of the sheathing is not necessarily due to chafe, though in certain cases the protective outer covering is removed by chafe, so allowing corrosion to start. Such chafe might be due to movement of the cable or to handling picked-up cable which has had the outer serving softened. The outer serving is often rendered ineffective by the action of marine growths, etc., but the point I wished to make in the paper was that the outer serving, besides being intact, must be waterproof, and must remain so in order to keep corrosive elements away from the sheathing wires. It is in the direction of producing a more waterproof outer serving that progress can be made.

Corrosion in deep water is not usual unless the bottom is of green mud; the effect on the core is not in the direction of rupture by pressure but rather in that of rupture by slow deterioration due to exposure to chemically subversive elements. In deep water a cable may work for years with the sheathing nearly corroded away. No trouble will be experienced until some seismic disturbance takes place or until the core, perishing more in one place than another, produces a fault and renders working difficult. On a good bottom, many miles of cable laid as long ago as 1870 is still in perfect condition, being in effect in cold storage at temperatures as low as 34° F.

With regard to fault (as distinct from break) localization, loop tests checked by overlap tests are usually employed. Where no second cable is available for a loop test the overlap is the only practicable test. For break tests the Lloyd–Black is in most general use, checked by the older methods.

The towed-electrode method is referred to in my reply to Sir George Lee.

We do not use the impedance/frequency localization test; it would only give good results on short lengths of gutta-percha-insulated telegraph cable. It is not correct to assume that faults occur in the main at the shore ends; they actually occur mainly in depths up to 200–300 fathoms. Some cables fortunately only have a small fraction of their length at each end in such depths, but in other cases there are many hundreds of miles of cable in this comparatively shallow water, as, for instance, in the Persian Gulf and the Malacca Straits.

Replying to Mr. Horn, the " A.L. balancing sea earth " is a small capacitance-resistance mesh to balance the " long sea earth " which is in the other side of the bridge. A " long sea earth " is used to earth the artificial line with a view to the earthing point being beyond the region of man-made interference (trams, etc.); if it is also convenient to have it in deep water it has advantages as regards susceptibility to lightning disturbances. The " short sea earth " in the apex of the bridge is used mainly to avoid disturbance *to* other circuits, the summation of the currents in the three wires being zero; for this purpose the nearer earthing point is sufficient. The short sea earth being in the apex of the bridge, any disturbances picked up in it have little effect on the receiving instrument.

As regards cable crossings, they are unfortunately unavoidable.

Referring to Fig. 33, the use of a given frequency is limited by the degree of ionization and absorption along the ray path, factors which have been shown to be very closely related to the degree of solar activity. When the limiting frequency for the route in question approaches that being used for communication, changes in signal level of the order of 60 to 80 db. may be experienced within less than 1 hour, thereby completely eclipsing those resulting from terminal improvements.

The Murray reed is of mild steel; there is no need to use elinvar, since all variations are corrected by bringing the number of vibrations under control of a clock. The name is retained as the reed was first designed by Donald Murray for his multiplex system.

With regard to Mr. Barlow's remarks, the standard voltage for long cables is 70 volts, and in certain cases where disturbances exist a voltage of 100 volts is used. Where the insulation is of the order of 800 megohms per nautical mile the use of such a voltage, which is far below the breakdown voltage, is not dangerous. Where a cable shows signs of becoming faulty, discretion is used, but it must be remembered that the stress on the cable falls rapidly with distance from the sending end; so that a far-distant fault is not subjected to any great pressure as long as the distant end is earthed through the small impedance of the receiving network.

In conclusion I wish to acknowledge the courtesy of the G.P.O. who so kindly placed at my disposal, both in London and in Leeds, connections between Electra House (Moorgate, London) and the Institution lecture theatres, thus enabling me to demonstrate automatic printing from South Africa on a wireless beam channel and also to make The Institution a terminal on a long chain of cables to Singapore and back again.

RESTRIKING VOLTAGE AT A TRANSFORMER SUBSTATION SUPPLIED BY A LONG FEEDER SYSTEM[*]

By L. GOSLAND, B.Sc., Associate Member.

(*Paper first received 12th January, and in revised form 10th March, 1939.*)

SUMMARY

The present paper gives the results of an investigation carried out by means of the restriking-voltage indicator[†] (r.v.i.), on the parameters determining rates of rise of voltage for switches in a large 33-kV substation fed through 16½ miles of 66-kV cables and three 50 000-kVA 66/33-kV transformers. The measurements were made on one set of transformers, and the results are used to deduce the transients of restriking voltage under the worst service conditions and are applicable in general to transformer substations fed by a long transmission system.

The highest rate of rise of voltage which appears to exist is 970 volts/microsec. (say 1 000 volts/microsec.). This will only occur when the rupturing capacity on the busbars is relatively small, the fault being supplied through a single transformer. The highest rate of rise of voltage encountered when the heaviest fault currents are involved (supply through three transformers) is 625 volts/microsec. The circuit oscillation frequencies encountered are quite low (8–14 kc./sec.), and it is concluded that for frequencies of this order it is quite safe to calculate transients of restriking voltage on the assumption that the main system parameters concerned (L_1, C_1) are approximately equal to their values measured at supply frequency. There is, however, some evidence that even at these relatively low frequencies the effective leakage inductance of the transformers is about 7 % less than the effective value at power frequency: and it is accordingly suggested that, until further information becomes available, caution should be observed in using 50-c./sec. values of transformer leakage inductance to calculate rates of rise of voltage when the natural frequency of the system concerned is much above 20 kc./sec. Methods are described by means of which transients of restriking voltage may be calculated in appropriate cases.

CONTENTS

(1) Introduction.
(2) Tests Made and Records Obtained.
(3) Analysis of Records.
  (*a*) Records taken on transformers alone:—
    (i) Phase to phase.
    (ii) Phase to phase-phase.
    (iii) Phase to phase-earth.
  (*b*) Records taken on complete transmission unit.
  (*c*) Recovery impedance.
(4) Discussion of Values of Parameters Deduced from Records.

CONTENTS—*continued.*

(5) Calculation of Inherent Transients of Restriking Voltage under Service Conditions (with reference to the worst switching conditions likely to arise for switches considered).
(6) Conclusions.
(7) Acknowledgments.
(8) References.
Appendix. Method of Calculation of Transients of Restriking Voltage for a Typical Substation of the Type Discussed in the Present Paper.

(1) INTRODUCTION

In connection with their survey of transients of restriking voltage at typical circuit-breaker locations, the E.R.A. were recently afforded the opportunity of taking some records with a restriking-voltage indicator (r.v.i.) at the new Valley Road (Streatham) substation of the County of London Electric Supply Co., Ltd., believed to be the largest substation in Great Britain.

The supply to the substation is arranged as shown in Fig. 1. The 33-kV bars at Valley Road are fed from the 33-kV bars at Barking by means of three similar transmission units each consisting of a 33/66-kV transformer at Barking, a 3-phase line 16½ miles long of 66-kV single-core cables, and 66/33-kV transformers at Valley Road. All the transformers have substantially the same characteristics, being of the same rating and impedance and made by the same maker. There is also one feed direct at 33 kV via an intermediate substation. For the measurements on which the present paper is based, the E.R.A. was given access to one complete 33/66/33-kV transmission unit. The measurements, which were made with the idea both of obtaining data on the transients of restriking voltage inherent in this particular system, and of studying the parameters controlling the transients in circuits of this type, were made on the Valley Road transformers by themselves, the 66-kV cable system by itself, and the complete transmission unit of two transformers with the intervening cable. Relevant system constants are presented in Table 1.

(2) TESTS MADE AND RECORDS OBTAINED

The tests were made in three groups; the first group, covering the 66-kV cable system by itself, has already been reported.[†] The only data concerning the cables which are used in the present paper are the effective surge impedances in various combinations; these are listed in Table 2.

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[*] Official communication (Ref. G/T102) from the British Electrical and Allied Industries Research Association.

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[†] See Reference (1).

[†] See Reference (2).

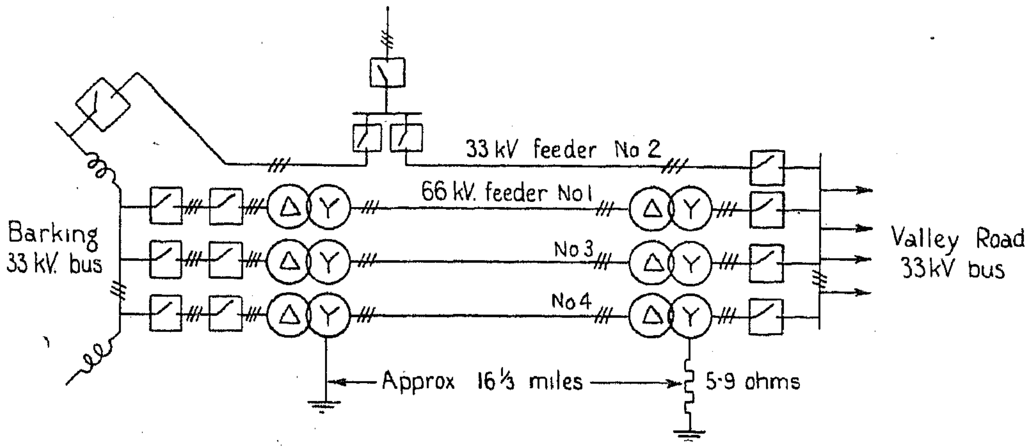

Fig. 1.—Schematic diagram showing connection between Barking power station and Valley Road substation.

Note: Barking transformers, three 3-phase, 33/66-kV, 50 000-kVA, 50 c./sec. Units of one make.
Valley Road transformers, three 3-phase, 66/33-kV, 50 000-kVA, 50 c./sec. Units of one make.

Table 1

System Constants (as supplied from the Records of the Undertaking).

1	2	3	4	5
Particulars	Equivalent star values per phase per mile			
	X	*L*	*R*	*C*
	ohm at 50 c./sec.	mH	ohm	μF
66-kV cables, Barking–Valley Road, 0·5 sq. in. ..	0·175	5·56	0·0865	0·720
66-kV cables, Barking–Valley Road, 0·35 sq. in. ..	0·181	5·76	0·1207	0·650
33-kV cables, Valley Road (per circuit)	0·180	5·72	0·0856	0·475
33-kV cables, Valley Road, total per phase	0·005	0·15	0·0023	0·0508
33/66-kV transformers, Valley Road*	0·217	6·9†	0·08‡	§

Length of 0·5-sq. in. 66-kV cable, 3 452 yards
Length of 0·35-sq. in. 66-kV cable 25 272 yards } Total 16⅓ miles (approx.)

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* From 33-kV side. † Effective leakage inductance. ‡ Total effective copper resistance. § Self-capacitance of winding not at present known.

Table 2*

Effective Surge Impedance of 3-Phase Line of Three 66-kV 0·35-sq. in. Single-Core P.I.D.L.S. Cables laid in Trefoil.

Phase combination	Effective surge impedance
	ohms
Phase to phase	41·4
Phase to phase-earth ..	19·7
Phase to phase-phase ..	31·7
3 phases to earth	7·7
Phase to earth	24·4

* All the values were obtained experimentally (see Reference 2) except the last, which was calculated.

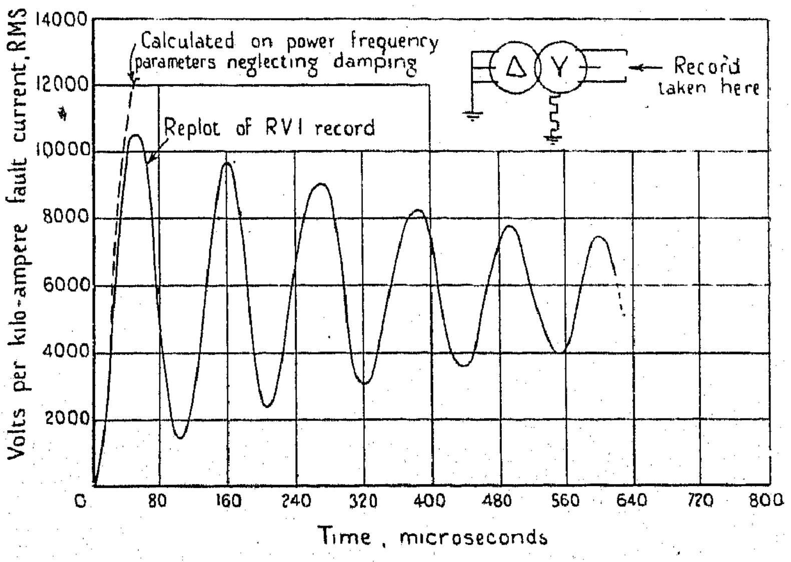


Fig. 2.—Replot of restriking-voltage-indicator record (No. 67) showing inherent transient of restriking voltage for transformer and cables to switch alone (phase-phase short-circuit). (Dotted line indicates front of transient calculated from power-frequency system constants, neglecting losses.)

The measurements on the Valley Road transformers by themselves were made by connecting together and to earth the three 66-kV terminals of the transformers, and applying the restriking-voltage indicator to the busbar spouts of the cables to the 33-kV side, in combinations representing the following switching operations:—

Interruption of phase-phase short-circuit.
Interruption of first phase of 3-phase short-circuit.
Interruption of first phase of phase-phase-earth short-circuit.

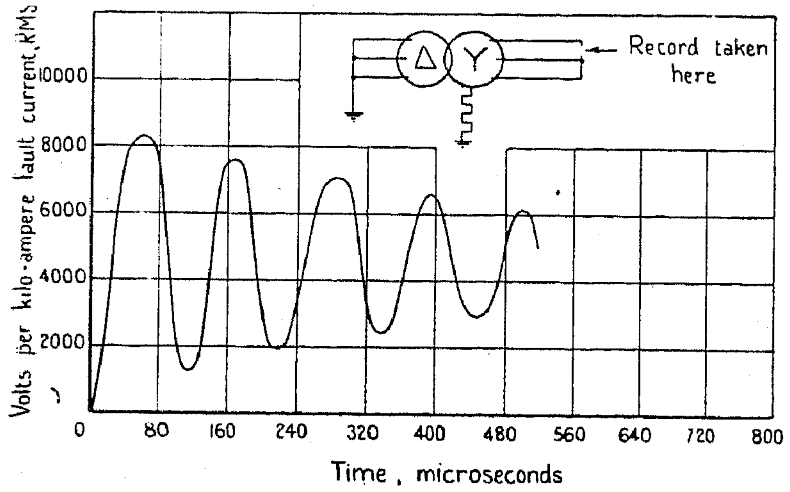


Fig. 3.—Replot of restriking-voltage-indicator record (No. 68) showing inherent transient of restriking voltage for transformers and cables to switch alone (1st phase to clear of 3-phase short-circuit).

These records represent the transients of restriking voltage which would obtain if the 33-kV busbars were fed through a single 66/33-kV transformer from a generator of zero impedance at the 66-kV terminals of the transformer. The records themselves are presented in Figs. 2 to 4, the voltage calibration being given in volts per kiloampere of fault current.

The records on the complete transmission unit were obtained by removing the short-circuit from the 66-kV terminals of the Valley Road transformers, and applying a short-circuit to earth at the 33-kV isolators between the 33-kV side of the transformer at the Barking end, and the Barking 33-kV bars. The restriking-voltage indicator was then applied to the 33-kV cable spouts at Valley Road, as before in phase combinations representing:—

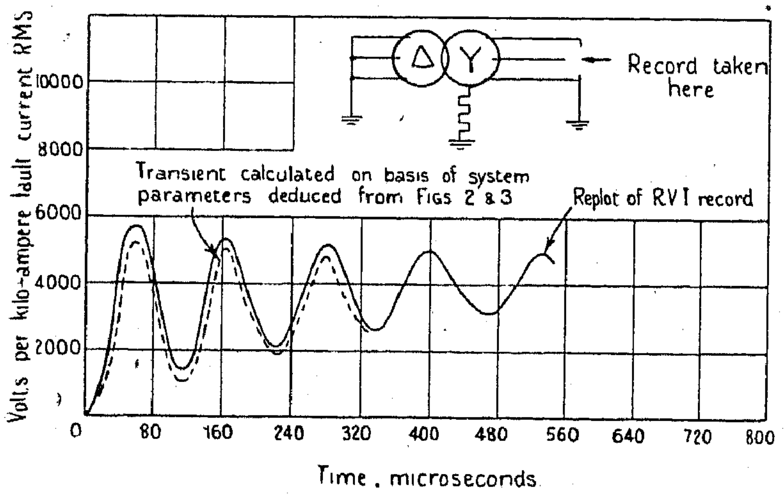


Fig. 4.—Replot of restriking-voltage-indicator record (No. 69) showing inherent transient of restriking voltage for transformers and cables to switch alone (1st phase to clear of phase-phase-earth short-circuit).

Interruption of phase-phase short-circuit.
Interruption of first phase of 3-phase short-circuit.
Interruption of first phase of phase-phase-earth short-circuit.
Interruption of phase-earth short-circuit.

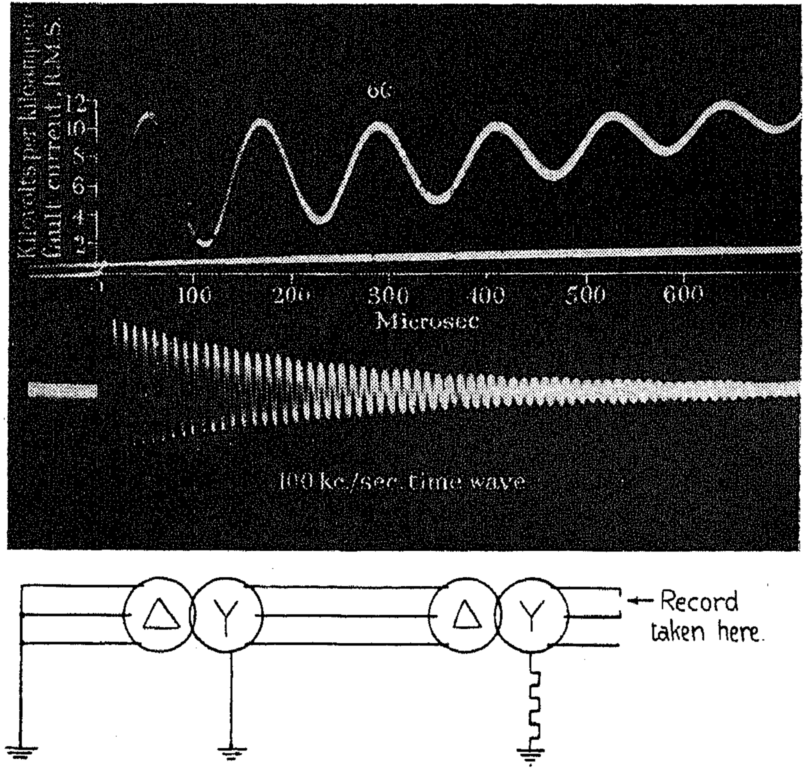


Fig. 5.—Restriking-voltage-indicator record (No. 60) showing inherent transient of restriking voltage for complete transmission unit (phase-phase short-circuit).

These records, which represent the transients that would obtain at the Valley Road busbars if they were fed by a single transmission unit from an infinitely large busbar at Barking, are shown in Figs. 5 to 8.

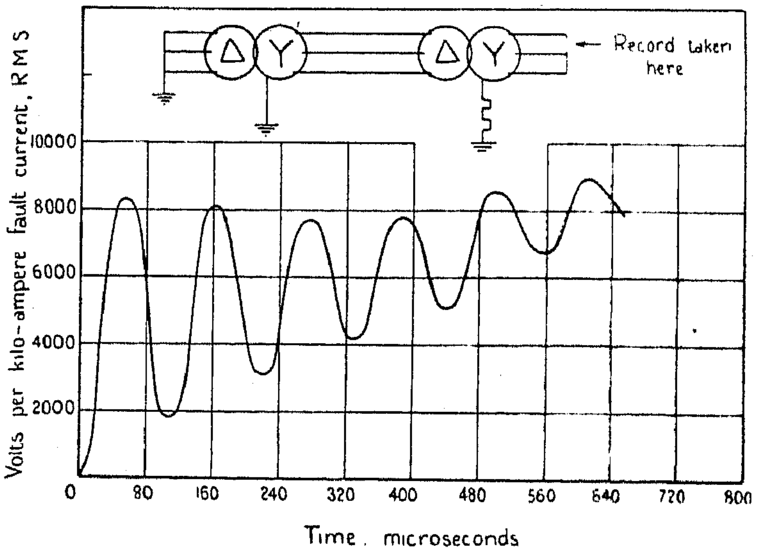


Fig. 6.—Replot of restriking-voltage-indicator record (No. 63) showing inherent transient of restriking voltage for complete transmission unit (1st phase to clear of 3-phase short-circuit).

(3) ANALYSIS OF RECORDS

(a) Records taken on Transformers Alone

(i) Phase to Phase.

The effective system parameters concerning the transformers alone can fairly easily be deduced from the records obtained.

Consider for example the phase-phase case. The conventional equivalent diagram for a transformer under power-frequency conditions is as shown in Fig. 9(*a*). Taking account of the fact that we are here dealing with transient conditions and a short-circuited transformer, the equivalent diagram should be as in Fig. 9(*b*). This is, however, unnecessarily complicated for our present purposes, and one of the diagrams of Figs. 9(*c*), 9(*d*), and 9(*e*), should suffice, according to whether it is necessary to take account of series resistance, parallel resistance, or both.

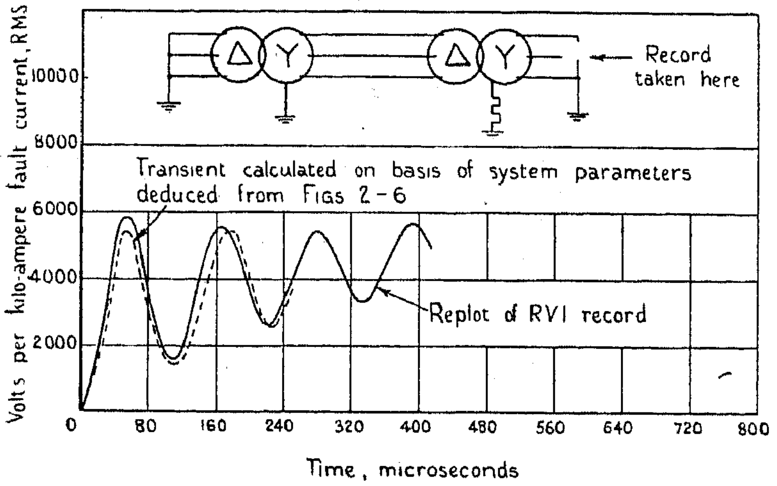


Fig. 7.—Replot of restriking-voltage-indicator record (No. 64) showing inherent transient of restriking voltage for complete transmission unit (1st phase to clear of phase-phase-earth short-circuit).

The record of Fig. 2 can be analysed into two terms:—

$$e_1 = A\{1 - \epsilon^{-\alpha t}\cos(\omega t + \phi)\}$$

and $e_2 = Bt$. Throughout the time with which we are concerned, e_2 is negligible; that is, the effective series resistance in the short-circuited transformer as represented in Fig. 9 is negligible and we can regard the transformer as being represented by Fig. 9(*d*).

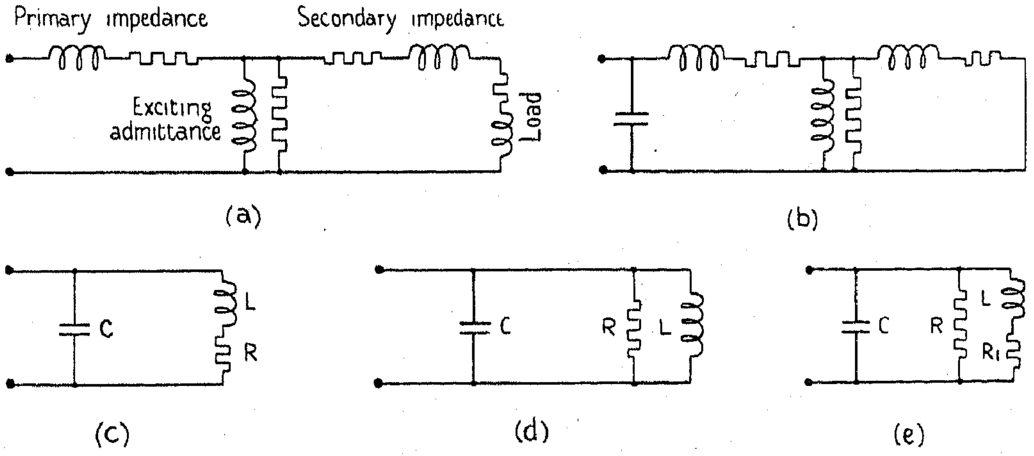


Fig. 9.—Transformer, equivalent diagrams.

The transient of restriking voltage is then given by

$$e = AL\left\{1 - \frac{\omega_0}{\omega}\epsilon^{-\alpha t}\sin(\omega t + \phi)\right\}$$

where

L = inductance,

$A = 2\pi f \times \sqrt{2} \times$ (r.m.s. current interrupted);

$\omega_0^2 = 1/(LC)$,

$\omega^2 = \omega_0^2 - \alpha^2$,

$\alpha = 1/(2RC)$,

R = effective shunt resistance,

C = capacitance.

By equating $1/(2RC)$ to the measured decrement of the oscillation of Fig. 2,

$$\omega = \sqrt{\left[\frac{1}{R^2C^2} - \frac{4}{LC}\right]}$$

to the measured frequency, and AL to the amplitude of the oscillatory component at zero time, the values of L_1, C_1, and R, can be deduced directly from the records; and, since we are here dealing with the phase-phase case, we can find the appropriate values per phase by multiplying by 0·5, 2, and 0·5, respectively.

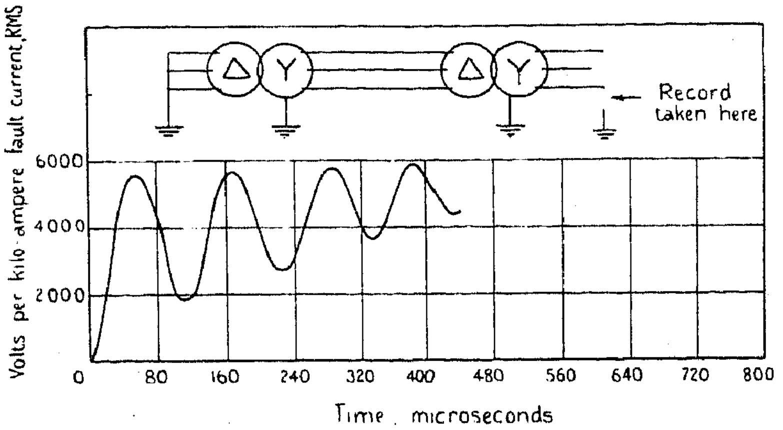


Fig. 8.—Replot of restriking-voltage-indicator record (No. 66) showing inherent transient of restriking voltage for complete transmission unit (phase-earth).

(ii) Phase to Phase-Phase.

In cases where the connections between transformer and switch are single-core cables or the equivalent (i.e. where we can assume that phase isolation is complete and that all capacitance is capacitance to earth), the effective values of L_1, C_1, and R, per phase can be obtained in this case (Fig. 3) by analysis exactly as in the phase-phase case, with the exception that the factors reducing the total to the per-phase quantities are now $\frac{2}{3}$, $\frac{3}{2}$, and $\frac{2}{3}$. The system parameters thus obtained are shown in Table 3.

This Table is intended to show the relation between the parameters representing the network during the occurrence of the restriking-voltage transient, and during steady-state conditions at 50 c./sec., respectively. The entries in the first six rows of cols. 3–9 are calculated from r.v.i. records, whilst those of the last row are obtained from the known power-frequency characteristics, in each case for a single transmission unit. The quantities in cols. 3–6 are those appropriate to a diagram such as that of Fig. 9(*e*); those in col. 7 represent the neutral earthing resistance. The value of recovery impedance (Z_R) in cols. 8 and 9 are those impedances which, when multiplied by the rate of change of current immediately prior to current zero, give the rate of rise of voltage after the current zero.

Table 3

CIRCUIT PARAMETERS DEDUCED FROM R.V.I. RECORDS, AND VALUES MEASURED AT SUPPLY FREQUENCY.

1	2	3	4	5	6	7	8	9
		Quantities per phase						
Record No.	Representing clearing of fault between	L	C	R^*	R'	$R_e^\dagger$	Z_R per phase	Z_R total
		mH	μF	ohms	ohms	ohms	ohms	ohms
67	Phase-phase	6·4	0·049	5 200	—	—	275	550
68	Phase-2 phases	6·35	0·051	5 240	—	—	265	400
69‡	Phase-earth	6·4	0·05	5 220	—	5·9	270	270
60	Phase-phase	6·4	0·053	4 850	7·2	—	260	520
63	Phase-2 phases	6·3	0·0495	5 500	7·2	—	275	415
64‡	Phase-phase-earth	6·4	0·05	5 000	7·0	5·9	260	260
66	Phase-earth	6·25	0·0495	7 500	7·8	5·9	270	270
Supply-frequency values		6·8§	0·05‖	10 000	5·4¶	5·9	265	—

Records 67, 68, 69, refer to transformer alone; 60, 63, 64, 66, to transformers with 66-kV feeders.

* Equivalent resistance per phase to give iron losses at working voltage.

† R_e = Earthing resistance. The normal earthing resistance was a metal grid resistance of 5·9-ohms. This was in service on the system when the measurements described were made, and a small 5·9-ohm resistor supplied by the E.R.A. was substituted for the tests.

‡ Values deduced from agreement between transient calculated on these values and the observed transient.

§ 9·8 % reactance on 50 000 kVA at 33 kV.

‖ 33-kV cables alone, no allowance for self-capacitance of transformer.

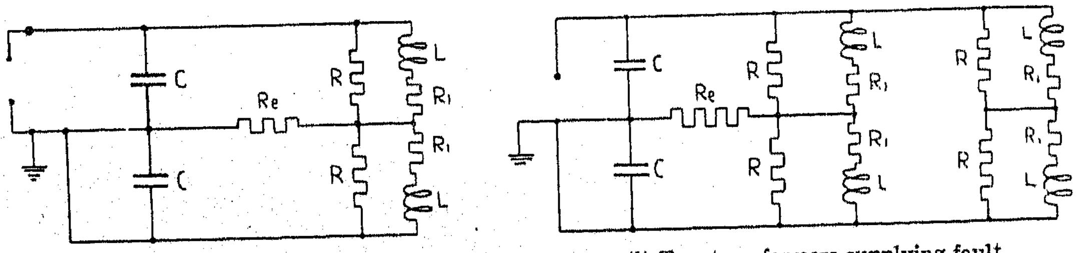
¶ Effective surge impedance of 66-kV cables (see Reference 2) reduced to primary voltage.

(iii) Phase to Phase-Earth.

The equivalent circuit diagram for this case (with supply through a single transformer) is as shown in Fig. 10(*a*) (since the only important capacitances are capacitances to earth, and phase inductances and effective parallel resistances are quantities to neutral). It has not so far been found possible to obtain an expression in general terms for the transient of restriking voltage in this case; but by making a numerical calculation it can be checked that the parameters deduced above in the phase-phase and 3-phase cases, used together with the known value of the neutral earthing resistance, give a transient which, as shown in Fig. 4, agrees quite closely with the observed transient.

(b) Records taken on Complete Transmission Unit

Analysis of these records to discover the system parameters is possible only over the first 350 microseconds or so (i.e. up to the time when the first waves reflected from the Barking end of the system appear at Valley Road). Over this time the cable system has the characteristics of a resistance viewed from the Valley Road end, and the equivalent diagram representing the system must now be that of Fig. 9(*e*). Here the transient of restriking voltage is given by



(*a*) One transformer supplying fault. (*b*) Two transformers supplying fault.

Fig. 10.—Equivalent diagrams for system at opening of 1st phase of phase-phase-earth short-circuit.

$$e = \frac{A}{C\omega_0^2}\left[1 - \frac{2\alpha R_1}{L\omega_0^2} + \frac{R_1 t}{L} + \epsilon^{-\alpha t}\left(\frac{R_1 - L^2\omega_0^2 - 2LR_1\alpha}{L^2\omega^2}\right)\sin(\omega t + \theta)\right]$$

where

$$\omega_0^2 = \frac{R + R_1}{LRC}; \quad 2\alpha = \frac{1}{RC} + \frac{R_1}{L}; \quad \omega^2 = \omega_0^2 - \alpha^2$$

$$\theta = \text{arc tan}\,\frac{\omega}{\alpha} + \text{arc tan}\,\frac{\omega R_1}{R_1\alpha - \omega_0^2 L}$$

Here again it is possible to analyse the records obtained in the phase-to-earth, phase-to-phase, and phase-to-phase-phase cases, to find the system parameters L, C, R, R_1 per phase, and the results of such an analysis are shown in Table 3. Here again the case of the phase-phase-earth short-circuit has not so far yielded to analytical treatment and, as before, recourse is made to the expedient of calculating this transient on the basis of the parameters obtained in the other cases, and showing that the result of the calculation agrees well with the observed transient (see Fig. 7). The values of the circuit parameters deduced as described above are listed in Table 3.

(c) Recovery Impedance

It is sometimes found convenient to obtain from the r.v.i. records a figure for the "recovery impedance"* of the circuit. The recovery impedance of a circuit is a fictitious ohmic resistance which, when multiplied by the rate of change of short-circuit current at the current zero (i.e. by $314\sqrt{2} \times$ r.m.s. short-circuit current for a 50-c./sec. system), gives the rate of rise of voltage across the terminals. The recovery impedances of the circuit on which the measurements here described were made, are given in Table 3, col. 9 showing the overall recovery impedance, and col. 8 showing the recovery impedance per phase, the neutral earthing resistance being regarded as a short-circuit where necessary. It will be seen that the recovery impedance regarded as a quantity per phase is practically constant at about 270 ohms for all the phase combinations on which measurements were made, the impedance of the neutral earth resistance and of the surge impedance of the 66-kV cables referred to the primary voltage being negligible in comparison. Whilst it is thus a convenient procedure to calculate a recovery impedance per phase, say, from considerations of the system on phase-phase short-circuit, and to use this to obtain rates of rise of voltage under other fault conditions, this method is not strictly valid, for instance, for fault conditions involving the earth connection when more than one transformer is supplying the fault, since the neutral point of one transformer only is usually earthed, and the effective impedances under phase-phase and under phase-phase-earth fault conditions are not strictly comparable [cf. Figs. 10(*a*) and 10(*b*)].

Where transients of restriking voltage under working conditions are discussed in Section (5), the figures for phase-phase-earth short-circuit are given both on the basis of a fixed recovery impedance per phase (deduced from the phase-phase case) and as calculated taking proper account of the relevant condition. It will be seen that the latter figures are rather higher than the former.

(4) DISCUSSION OF VALUES OF PARAMETERS DEDUCED FROM RECORDS

It will be seen from Table 3 that the values deduced for the circuit parameters per phase from records taken in various phase combinations are, all things considered, remarkably consistent, and that they agree reasonably well with the supply-frequency values. No attempt should be made to draw conclusions from the variation between values deduced from different phase combinations. It is, however, to be noted that the effective inductance per phase of the transformer under the transient conditions here discussed is only about 93 % of the leakage inductance of the transformer, and that the effective capacitance per phase of the system is just under the value given for the capacitance of the 33-kV cables alone. Now whilst it is not surprising that the effective inductance per phase of the transformers should vary between power-frequency and transient conditions, it is surprising that the effective capacitance is not increased beyond the cable capacitance by stray capacitances and, for instance, the self-capacitance of the transformer winding.* It is, however, just possible that since the cable capacitance figure given in the table was obtained by multiplying the cable capacitance per unit length by the total length laid per phase, the reduction of capacitance of the portions of cable inserted in the end boxes, etc., is sufficient to compensate for the stray capacitances. The reduction in effective inductance must be real,† since to obtain frequencies of the observed values with an inductance of the power-frequency value it would be necessary for the effective capacitance of the circuit to be considerably less than the power-frequency capacitance of the cables by themselves, and this is very unlikely.

The reduction of the effective inductance of the transformers raises an interesting point concerning the agreement between restriking-voltage-indicator tests and actual switching conditions on transformers. The peak voltage recorded by the r.v.i. is proportional to the effective inductance at the frequency of the transient. The peak voltage under switching conditions should be proportional to the voltage dropped in the transformer reactance. Measurements taken by the E.R.A. show (see Fig. 11) that the effective inductance of a large transformer may drop by as much as 30 % between power frequency and the resonant frequency of the short-circuited transformer with no external capacitance, and the relation between r.v.i. measurements and actual inherent transients under such conditions requires some investigation. Under the conditions of the present tests the difference due to this cause is not likely to be more than a few per cent.

There is no apparent reason for the difference between the value (5·4 ohms) of the effective surge impedance of the 66-kV cable referred to the primary voltage and the value (7·2 to 7·8 ohms) found for the effective series resistance of the transformer with cables; the subject will be investigated further, possibly in connection with future tests involving transformers with overhead lines, where the quantities concerned will be larger and more easily studied. In the present tests it was not possible to deduce this quantity with any great accuracy.

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* See Reference (3).

* Although the self-capacitance of the transformer winding is not at present known, it is not likely to be much more than a few per cent of the cable capacitance.

† An investigation carried out subsequently to the preparation of the present paper, and now approaching completion, has shown that this reduction in inductance does in fact take place, and can be calculated with some accuracy from the dimensions of the transformer.

In order to bring out the effect of the alteration in circuit parameters shown by the r.v.i. measurements here described, the front of the transient of restriking voltage at the opening of a phase-phase short-circuit as it would be if the system parameters under transient conditions were the same as their normal power frequency value, and if losses in the circuit were negligible, has been worked out and is plotted in Fig. 2 with the transient given by the r.v.i. It will be seen that the normal system constants give a higher peak voltage and a rather higher rate of rise.

It is noteworthy that in none of the records obtained was there any sign of a transformer oscillating at more than a single frequency, although it is known that it is possible to produce resonance of transformers at more than one frequency in certain cases.

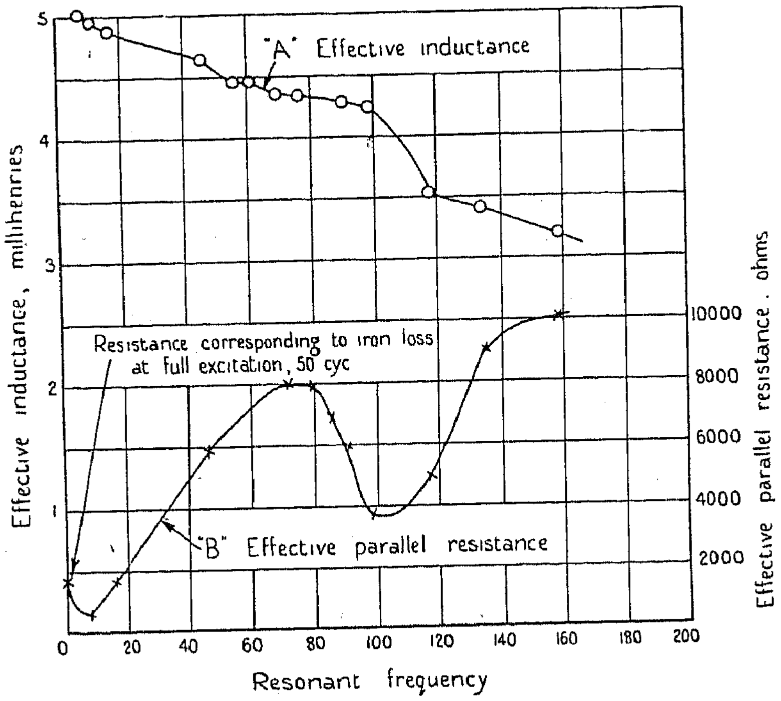

Fig. 11.—Variation with frequency of (*a*) effective inductance and (*b*) effective-parallel resistance of short-circuited transformer 6 600/12 700 V, 4 000 kVA, 1·5 % reactance.

The effective parallel resistance per phase accounting for the observed damping is of the order of 5 000–6 000 ohms. In the transformers under consideration the total iron losses are about 90 000 watts (i.e. equivalent to about 12 000 ohms per phase at 33 kV). It is thus reasonable to suggest that for the purpose of calculating transients of restriking voltage in systems giving rise to frequencies of the order here encountered, the effective parallel resistance per phase of the transformers should be taken as half the resistance equivalent to the iron loss at power frequency.

(5) CALCULATION OF INHERENT TRANSIENTS OF RESTRIKING VOLTAGE UNDER SERVICE CONDITIONS (WITH REFERENCE TO THE WORST SWITCHING CONDITIONS LIKELY TO ARISE FOR SWITCHES CONSIDERED)

The r.v.i. records examined above have provided information regarding system parameters. They will also provide direct information regarding restriking-voltage transients under service conditions, but only for faults which are supplied through the one transmission unit under consideration. Since this does not give either the heaviest fault condition or the highest rate of rise of voltage for any breaker at Valley Road, some calculation is necessary to obtain inherent restriking-voltage transients under service conditions.

It will be seen from Fig. 1 that the substation 33-kV bars are fed by three 66/33-kV feeder units and one 33-kV feeder. The heaviest fault-current conditions arise when faults are fed by all of these; but whilst the presence of the 33-kV feeder on the bars will only increase the fault current by a fairly small percentage above the fault current fed through the 66/33-kV feeder units alone, it will, however, cause a large reduction in the rate of rise of voltage (down to less than 20 % of the values here shown) by reason of its low surge (i.e. recovery) impedance. In calculating fault currents and rates of rise of voltage under service conditions, therefore, we shall neglect the presence of the 33-kV feeder, remembering that when it is connected to the busbars the fault currents will be slightly increased, whilst the rate of rise of voltage will be very considerably reduced. In making these calculations it is necessary to assume that the effective inductance of each transformer, and its effective parallel resistance, is the same over the range of oscillation frequencies which our results yield (8–14 kc./sec.) as at the frequency shown by r.v.i. records taken on No. 4 unit alone (8 kc./sec.). This is a fairly reasonable assumption, although, as mentioned in Section (4), it is possible that

Table 4

FAULT CURRENTS AT VALLEY ROAD.
FAULTS ASSUMED FED BY 66/33-KV FEEDER UNITS ONLY, AND FROM VALLEY ROAD END ONLY (I.E. END OF FAULTY UNIT REMOTE FROM VALLEY ROAD IS ISOLATED).

Type of fault	Symmetrical r.m.s. fault current when fed through—		
	1 unit	2 units	3 units
	amp.	amp.	amp.
Phase-phase ..	2 745	5 060	6 880
3-phase	3 280	5 840	7 900
Phase-earth ..	2 250	2 810	3 090
Phase-phase-earth*	3 860	5 860	6 690
	2 800	4 260	4 840

* The two current values given correspond to the two phases.

Table 5

LENGTH AND EFFECTIVE CAPACITANCE PER PHASE OF 33-KV CABLE TAILS AT VALLEY ROAD.

Transmission unit	Total length per phase	Capacitance per phase
	yards	μF
No. 1	107	0·0288
No. 3*	75	0·0202
No. 4	188	0·0508

* No. 2 is a 33-kV feeder.

the effective inductance of the transformers and their parallel resistances may be considerably reduced at higher frequencies.

The fault currents at the substation busbars under various fault conditions are given in Table 4, for the cases when the busbars are fed through one, two, and three 66/33-kV transmission units. These fault currents are calculated on the assumption that the fault is not being fed simultaneously from any other point on the system.

Table 6

FAULT CURRENTS AND RATES OF RISE OF RESTRIKING VOLTAGE UNDER CONDITIONS GIVING RISE TO HIGHEST RATE OF RISE OF VOLTAGE ENCOUNTERED IN SUBSTATION (NO. 3 FEEDER BREAKER OPENING LAST TO CLEAR FAULT ON BUSBARS. IT IS ASSUMED THAT NO. 3 TRANSFORMER HAS ITS NEUTRAL EARTHED).

1	2	3	4
Type of breaker operation	R.M.S. fault current in phase concerned	Rate of rise of voltage (tangential method)	Peak voltage reached at approximately the rate of col. 3
	amp.	volts/μ sec.	volts
Opening of phase-phase fault	2 745	970	30 500
Opening of first phase of 3-phase fault	3 280	865	27 500
Opening of first phase of phase-phase-earth fault*	3 860 2 800	680 495	21 500 15 600
Opening of phase-earth fault	2 250	395	12 500

* The two values of current given correspond to the two phases, as it is not known beforehand which phase will clear first.

Table 7

FAULT CURRENTS AND RATES OF RISE OF VOLTAGE, UNDER CONDITIONS GIVING RISE TO THE HEAVIEST FAULT CONDITION WHICH IS ASSOCIATED WITH HIGH RATE OF RISE OF VOLTAGE FOR THE *INCOMING* FEEDER BREAKERS (NO. 4 FEEDER BREAKER OPENING TO CLEAR FAULT BETWEEN ITSELF AND NO. 4 TRANSFORMER. FEED TO BUSBARS MAINTAINED BY NOS. 1 AND 3 TRANSFORMERS WITH NO OUTGOING FEEDERS ON BARS).*

1	2	3		4	
Type of breaker operation	R.M.S. fault current in phase concerned	Rate of rise of voltage (tangential method)		Peak voltage reached at approximately the rate of col. 3	
	amp.	volts/μ sec.		volts	
Opening of phase-phase fault	5 060	800		27 500	
Opening of first phase of 3-phase fault	5 840	690		23 500	
		(a)‡	(b)‡	(a)‡	(b)‡
Opening of first phase of phase-phase-earth fault†	5 810 4 260	460 335	465 340	15 800 11 500	19 500 14 500

* Slightly heavier fault currents will be obtained if the 33-kV feeder from Barking is also supplying the fault: the rate of rise of voltage will, however, in this case be very much lower.

† The two values of current given correspond to the two phases, as it is not known beforehand which phase will clear first.

‡ The figures in column (a) are calculated on assumption of fixed recovery impedance per phase, deduced from the phase-phase case. The figures in column (b) are calculated taking proper account of method of neutral earth connection.

The three transmission units, whilst they are substantially identical so far as power-frequency impedances are concerned, differ in the length of cable between the 66/33-kV transformers and the 33-kV busbars. These lengths, and the relative capacitances, are shown in Table 5. It will be clear that a fault fed by No. 3 feeder alone will be associated with a higher rate of rise of voltage than a fault fed by No. 1 or No. 4 feeder alone, since in the former case the product LC is smaller and hence the oscillation frequencies are higher than in the latter; and similarly a fault fed by No. 3 feeder alone will have a higher rate of rise of voltage than one fed by No. 3 and No. 4 together, and so on. The highest rate of rise of voltage encountered in the substation will thus occur in the unlikely event of a busbar fault occurring, and No. 3 feeder circuit-breaker being the last to open on it. The transients of restriking voltage which would arise under these conditions have been worked out, and the rates of rise of voltage (measured by the tangential method) are given in Table 6, in which also appears a figure showing the peak voltage reached at approximately the given rate in each case. A typical transient (that of

Table 8

FAULT CURRENTS AND RATES OF RISE OF VOLTAGE UNDER CONDITIONS GIVING RISE TO THE HEAVIEST FAULT CONDITION WHICH IS ASSOCIATED WITH HIGH RATE OF RISE OF VOLTAGE FOR THE *OUTGOING* FEEDER BREAKERS (BUSBARS FED THROUGH THREE 66/33-kV TRANSFORMERS: NO OTHER OUTGOING FEEDERS ON BARS).*

1	2	3		4	
Type of breaker operation	R.M.S. fault current in phase concerned	Rate of rise of voltage (tangential method)		Peak voltage reached at approximately the rate of col. 3	
	amp.	volts/μ sec.		volts	
Opening of phase-phase fault	6 880	625		26 000	
Opening of first phase of 3-phase fault	7 900	545		22 500	
		(a)‡	(b)‡	(a)‡	(b)‡
Opening of first phase of phase-phase-earth fault†	6 690 4 840	304 220	360 260	12 700 9 150	18 000 13 000

* Slightly heavier fault currents will be obtained if the 33-kV feeder from Barking is also supplying the fault; the rate of rise of voltage will, however, in this case be very much lower.

† The two values of current given correspond to the two phases, as it is not known beforehand which phase will clear first.

‡ The figures in column (*a*) are calculated on the assumption of fixed recovery impedance per phase, deduced from the phase-phase case. The figures in column (*b*) are calculated taking proper account of the method of neutral earth connection.

the voltage across the first phase to clear of a phase-phase-earth fault, assuming the phase with smaller current, phase angle, and rate of rise of voltage clears first) under these conditions is plotted in Fig. 12. The first 50 microseconds or so of this transient (which is plotted to an enlarged time scale in the same figure) is almost exactly half the transient at the clearing of the phase-phase short-circuit, which latter, however is divided between two poles of the breaker in series. The transient is plotted over 200 microseconds only, since shortly after this time the effects of voltage waves reflected back along the cable from the power station begin to appear.

The heaviest fault-current conditions to which the breakers on the incoming feeders are subjected occurs when a breaker is opening to cut out a faulty feeder, the breaker at the generating station end having already opened. There the most severe restriking-voltage conditions occur when the faulty feeder is No. 4 (since Nos. 1 and 3 feeders give the minimum capacitance across the switch) and when (a most unlikely occurrence) there are no outgoing feeders on the busbars. The rates of rise of restriking voltage under these conditions are given in Table 7, and a typical transient (the transient of voltage across the two breaks opening a phase-phase short-circuit) is shown in Fig. 13.

The circuit-breaker on any outgoing 33-kV feeder will have to contend with rates of rise of voltage much of the same magnitude as those given in Tables 6 and 7 when they open on a fault on the feeder they control, with one or two transmission units feeding the 33-kV busbars, and with no other outgoing feeders on the bars. The most severe fault condition occurs when three transmission units are feeding the bars; fault currents and rates of rise of voltage are then as shown in Table 8. A typical calculated transient of restriking voltage (that for the phase-phase case) is shown in Fig. 14.

From what has been said above it will be clear that there is no simple answer to the question " What is the rate of rise of voltage on a given set of busbars? " The rates of rise of voltage (even for a given type of fault, say, a phase-phase fault) differ considerably with the arrangement of the feed to the substation, and the highest rate of rise of voltage need not be, and often is not, associated with the connection giving the heaviest fault current.

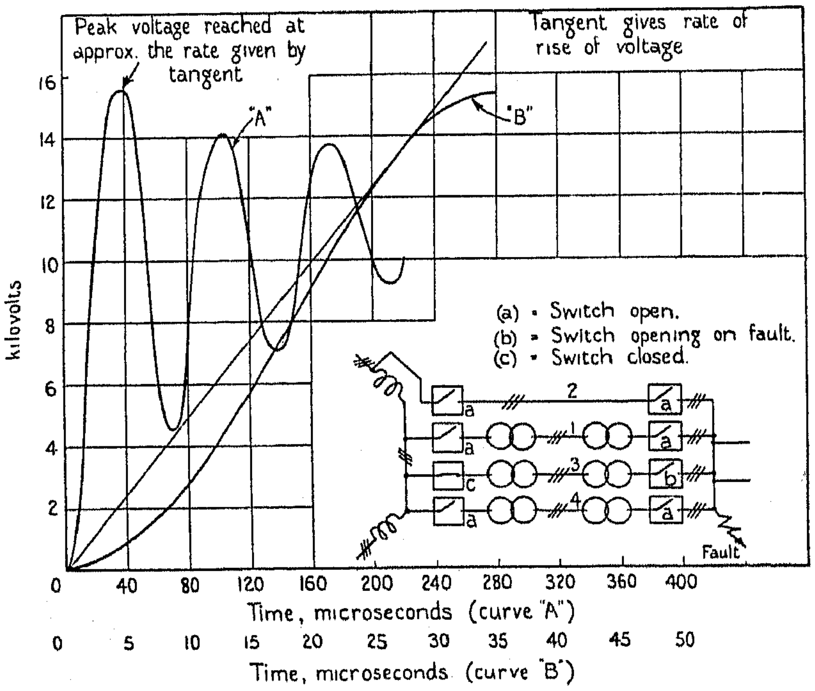

Fig. 12.—Calculated transient of restriking voltage. (1st phase to clear of phase-phase-earth short-circuit, fault fed by No. 3 Feeder alone. Assuming that phase with smaller current clears first.)

(6) CONCLUSIONS

(*a*) The front of the transient of restriking voltage experienced by breakers in substations of the type here discussed can be calculated to within an accuracy of ± 5 % by using the methods shown in the Appendix. The calculations given in the paper are applicable to transformer substations fed by long transmission systems, and although the present paper deals with the case where the transmission system consists of single-core cables, the method described is capable of being used to cover the cases of feeders consisting of 3-core cables or of overhead lines, the only difference between the three cases being the correction factors used to relate the effective to the nominal surge impedances of the feeders (see Appendix).

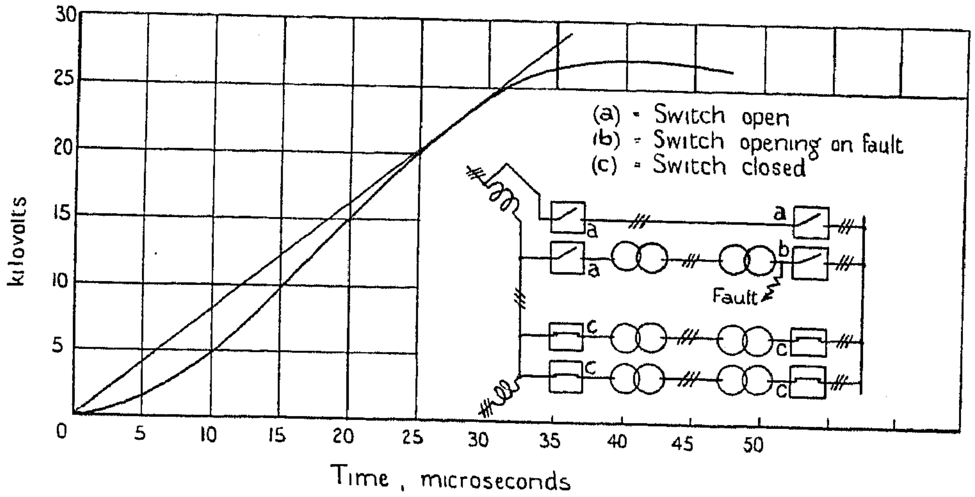

Fig. 13.—Calculated transient of restriking voltage. [Phase-phase fault feeding two transformers (Nos. 1 and 3). (Heaviest fault for high rate of rise on incoming feeder breakers.)]

(*b*) R.V.I. measurements show rates of rise of voltage up to 900 volts/μsec., associated with circuit oscillation frequencies up to 14 kc./sec., under phase-phase fault conditions on the 33-kV busbars here discussed. These rates of rise, the highest with which any circuit-breaker in the substation will have to deal, occur when a single transmission unit is feeding the busbar and a circuit-breaker operates to clear a busbar fault from the supply. Under these conditions, therefore, the fault kVA will be about one-third of the maximum fault kVA at the substation (when the supply is given through all four existing feeders from Barking).

(*c*) The heaviest fault kVA at the substation can only arise when a breaker on an outgoing feeder operates to clear a fault on the feeder whilst the supply to the busbars is maintained through the three 33/66/33-kV transmission units and the 33-kV feeder shown in Fig. 1. Here the rate of rise of voltage will be quite low (less than 100 volts/μsec.) by reason of the presence of the 33-kV feeder. If the 33-kV feeder is not in service, the fault kVA will be little reduced, whilst the rate of rise of voltage under phase-phase fault conditions will become 625 volts/μsec.

(*d*) The actual circuit parameters determining transients and rates of rise of restriking voltage are slightly different from the nominal (supply frequency) system constants, the effective transformer inductances and the shunt resistance representing losses which in both cases are lower than the nominal values. The differences in the present instance (due to the relatively low frequencies of 8–14 kc./sec. involved) are not sufficiently great to affect the rates of rise of voltage seriously. In the calculations of restriking-voltage transients described in Section (4), the impedance values deduced from the r.v.i. records were used.

(*e*) If the system constants (as measured at supply frequency) indicate that the transient of restriking voltage in a system containing transformers is likely to contain oscillatory terms of frequency less than 20 kc./sec., reasonable reliance can be placed on rates of rise of voltage calculated from these constants, as described in the Appendix. If, however, frequencies much above 20 kc./sec. appear, calculated rates of rise should be regarded with some suspicion.

(*f*) For a given switch, the service condition giving the highest rate of rise of voltage need not be, and often is not, the condition giving the heaviest fault current.

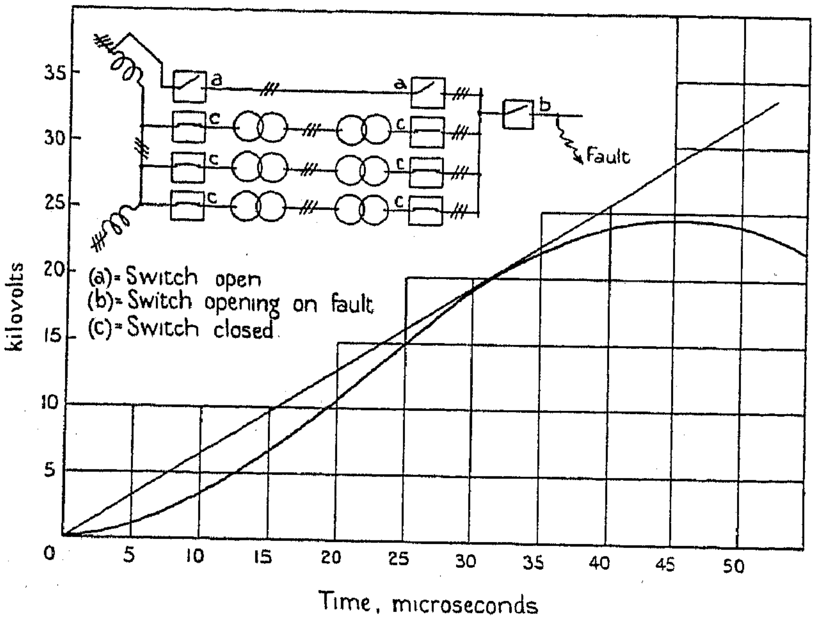

Fig. 14.—Calculated transient of restriking voltage. [Phase-phase fault on outgoing feeder, fed by three transmission units (heaviest fault for high rate of rise of voltage on outgoing feeder breakers.)]

(*g*) It is only under very unusual conditions of plant connection that switchgear discussed here would have to contend with the rates of rise of voltage given above. For most operations under fault conditions the rates of rise of voltage would be very considerably lower, of the order of 100 volts/μsec.

(7) ACKNOWLEDGMENTS

The Electrical Research Association is indebted to the County of London Electric Supply Co., Ltd., and to Mr. W. J. H. Wood, Engineer-in-Chief, for permission to make the measurements on which this paper is based, and also to members of the Company's staff for their co-operation in making the measurements.

The work described forms part of the investigation into the phenomena of arc rupture which is being carried out on behalf of the E.R.A. by Dr. W. B. Whitney, to whom the author is indebted for helpful discussions and criticisms during the course of the work. He wishes also to acknowledge the great assistance given by his colleague Mr. W. M. F. Dunne during the preparation of the paper.

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APPENDIX

Method of Calculation of Transients of Restriking Voltage for a Typical Substation of the Type discussed in the Present Paper

Consider a substation fed by n identical transmission lines and step-down transformers, differing only in the length of cable between the transformers and the substation busbars.

The heaviest fault condition will occur for a switch clearing a fault on an outgoing feeder, when there are no other feeders on the busbars. The transient of restriking voltage under phase-phase fault conditions can be obtained as described below.

Let

I (amperes) = r.m.s. phase-phase fault current calculated in the normal manner.

f = supply frequency, c./sec.

X (ohms) = leakage reactance per phase of one transformer.

L (henrys) $\doteq x/(2\pi f)$ be the leakage inductance per phase of one transformer.

$2R$ (ohms) = the equivalent shunt resistance per phase accounting for the iron losses of one transformer at the busbar voltage.

L_T (henrys) = star inductance per unit length of the incoming feeder at the transmission voltage.

C_T (farads) = star capacitance per unit length of feeder.

S = step-down ratio (transmission voltage/busbar voltage).

$Z_T = \sqrt{\left[\frac{L_T}{C_T}\right]}$ = surge impedance of feeder per phase at transmission voltage, ohms.

$\frac{1}{S^2} \cdot Z_T$ = surge impedance of feeder per phase referred to busbar voltage.

$R_1 = \frac{K}{S^2} \cdot Z_T$ = resistance equivalent to surge impedance of incoming feeder.

K = a factor $\simeq 0 \cdot 75$ for single-core cables (see Reference 2).

$\simeq 1 \cdot 1$ for 3-core cables (see Reference 4).

For overhead lines K should at present be taken as unity. There are as yet no data available on this point.

C = mean capacitance to earth per phase per transformer on busbar side ($1/n \times$ sum of capacitances to earth per phase of cables to the transformers and of the busbars, n being the number of transformers).

Then the transient of restriking voltage for a phase-phase short-circuit is given by

$$e = \frac{2}{n} \cdot \frac{2\pi f I \sqrt{2}}{C\omega_0^2}\left[1 - \frac{2\alpha R_1}{L\omega_0^2} + \frac{R_1 t}{L} + \epsilon^{-\alpha t}\left\{\frac{R_1 - L^2\omega_0^2 - 2LR_1\alpha}{L^2\omega^2}\right\} \sin(\omega t + \theta)\right]$$

where

$$\omega_0^2 = \frac{R + R_1}{LRC}; \quad 2\alpha = \frac{1}{RC} + \frac{R_1}{L}; \quad \omega^2 = \omega_0^2 - \alpha^2$$

$$\theta = \arctan\left(\frac{\omega}{\alpha}\right) + \arctan\left\{\frac{\omega R_1}{R_1\alpha - \omega_0^2 L}\right\}$$

This formula holds for a time $t = 2l\sqrt{(L_T C_T)}$ sec., where l is the length of the feeder in the units to which $L_T C_T$ above are referred. The formula should be used with caution for values of ω above $1 \cdot 25 \times 10^5$.

If the voltage given by the above expression is plotted to a base of time, the tangent drawn from the origin to the rising curve gives the rate of rise of voltage in volts per unit time (say P volts/μsec.).

The corresponding rate of rise of voltage for the first phase to clear of a 3-phase fault is given by

$$P_3 = \frac{3}{4} \cdot \frac{I_3}{I} P$$

where I_3 is the 3-phase fault current.

Transients of restriking voltage for fault conditions involving the earth connection can usually only be calculated by operational methods; and it is not found practicable to give formulae similar to the above to cover these cases. A fair idea of the restriking-voltage conditions at any point can, however, be gathered from a knowledge of the restriking-voltage transient for a phase-phase short-circuit only.

OUTPUT AND EFFICIENCY OF THE SPLIT-ANODE MAGNETRON OSCILLATING IN THE DYNATRON REGIME[*]

By A. F. HARVEY, B.Sc.(Eng.), Graduate.[†]

(*Paper first received* 21*st September, and in revised form* 15*th November,* 1938.)

SUMMARY

An account is given of the performance of the split-anode magnetron when working at frequencies such that transit time can be neglected. An accurate and convenient method is described of determining this performance from the measurement of valve resistance at power frequencies. A series of results for one valve are included; these show the general influence of the various operating conditions.

The anode modulation and frequency stability of the valve are discussed, while some measurements at radio frequency are given and the agreement of the two methods is found to be good.

(1) INTRODUCTION

The split-anode magnetron consists of a central filament with two hemi-cylinders external to it. In operation an axial magnetic field is applied and it is well known that as the field strength is increased the electron paths for a given anode voltage become more curved until finally, at a value called the " critical field," they just graze the anode and return to the filament; the anode current then becomes small. If the filament diameter is small compared with the anode diameter d, then Hull showed that this value of field is given by

$$H = \sqrt{\left[\frac{181V}{d^2}\right]}$$

where H is measured in gauss, V in volts, and d in cm., and is independent of space-charge conditions.

Under this condition of " cut-off " the valve resistance of each half anode can become negative over a certain range, and if a tuned circuit of sufficient dynamic impedance is connected between the anodes, as shown in Fig. 12, sustained oscillations are possible. From similarity with the negative-resistance triode and tetrode these are commonly referred to as " dynatron oscillations." The mechanism by which this effect is produced in the valve is partly understood[‡] and will not be discussed further.

Provided the frequency is less than, say, 10 Mc./sec.[§] the effects of electron transit time can be neglected and the valve performance can be predicted by measurement made at power frequencies, or even from the static characteristics.

The valve used in the experiments (Osram type CW.10) had an anode diameter of 1 cm. and a length of 2 cm., with a rated dissipation of 50 W. An iron-cored electromagnet was used for the field, the air-gap being 3·8 cm. long and the diameter of the pole-pieces 10 cm. The field strength was determined from the magnetizing current, a previous calibration having been made by a fluxmeter, care being taken to reduce the error due to magnetic hysteresis.

(2) THE STATIC CHARACTERISTICS

An account of these has been given by E. C. S. Megaw[‡] and as an insight to the dynatron oscillation they will be briefly dealt with. Fig. 1 shows the currents taken by each anode for three different values of magnetic field (including zero). It is seen that with the magnetic field the lower-voltage electrode takes the larger current except when the amplitude of alternating voltage is large. Fig. 2 gives the cycle of currents under a given set of operating conditions. The full-line curve represents the power component of current in the tuned circuit, and Fourier analysis of this enables the output of the valve to be determined. Since the anode current is sensibly cut off when the valve is not oscillating, it is clear that the battery supplies power by virtue of the rectified current which results from the oscillation, and this is shown on the same diagram. The valve performance, however, can be predicted more readily from other experimental curves which will now be described.

(3) METHOD OF DETERMINATION OF VALVE RESISTANCE

It is known that for a tuned circuit of low power factor the fluctuations of potential of the anode to which it is connected are nearly simple harmonic. The valve current, however, is complex and the fundamental component only supplies the power absorbed in the external circuit and load. This gives rise to a quantity, the fundamental component of valve resistance, which in the case of the magnetron, as we have shown above, is negative.

It will be understood that the amplitude of oscillation which can be maintained in a circuit must have that value for which the fundamental component of resistance of the valve is equal and opposite to the dynamic resistance of the circuit. Hence a low-frequency measure-

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[*] The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

[†] Engineering Laboratory, Oxford University.

[‡] See, for example, E. W. B. GILL and K. G. BRITTON: *Journal I.E.E.*, 1936, vol. 78, p. 461; also K. POSTHUMOUS: *Wireless Engineer*, 1935, vol. 12, p. 126.

[§] In the absence of magnetic field, the transit time is given approximately by the equation

$$T = \frac{2 \cdot 5}{10^2} \cdot \frac{d}{\sqrt{V}} \text{ microsec.}$$

The critical field increases T by a factor of about 4; hence if $V = 100$, $d = 0 \cdot 5$, is of the order 1/200 microsec.

[‡] *Journal I.E.E.*, 1933 vol. 72, p. 326.

ment of this fundamental component will enable the performance of the magnetron at any frequency appreciably less than the inverse of the transit time of electrons to be predicted.

The fundamental component of resistance can be measured at power frequencies by a dynamometer, for if the complex anode current passes through the suspended coil and the field due to the fixed coils alternates simple-harmonically at the fundamental frequency of the anode current, the resulting couple is due only to that fundamental component. A fuller description of this method as applied to triodes has been given previously.*

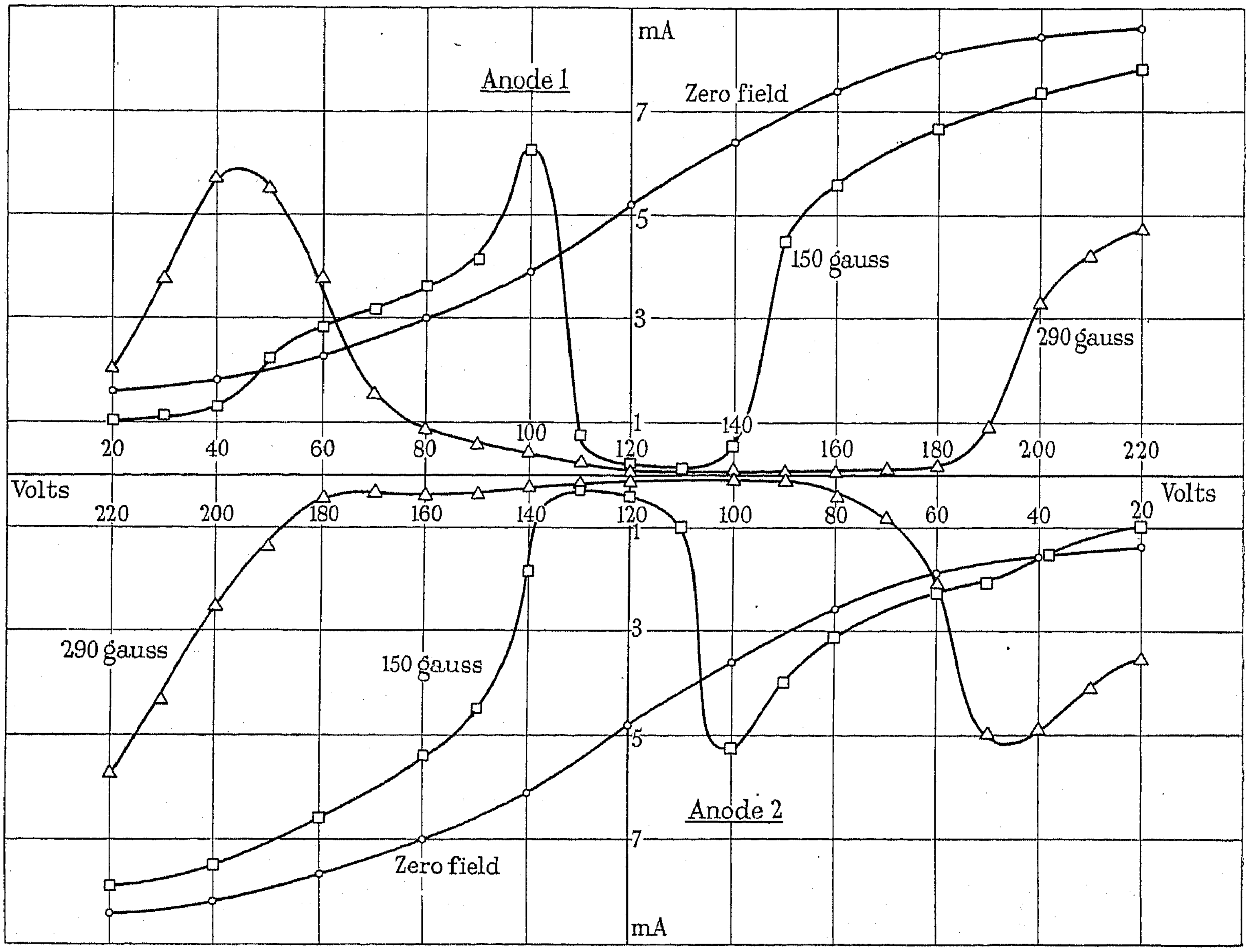

Fig. 1.—Static curves of magnetron. Filament emission 10 mA.

The circuit diagram of the measuring system is shown in Fig. 3: it is self-explanatory and need not be described in detail. The H.T. supply was connected to the centre tap in the suspended coil, and the suspension strips were used to connect the two ends of the coil, through identical windings of a transformer, to the anodes. The moving coil had an inductance of 18 mH and a resistance of 60 ohms, and the fixed coils had an inductance of 12 μH: thus the respective reactances were small compared with the resistances in series with them.

The negative resistance of the valve at any assigned amplitude was determined by matching the observed deflection with that which resulted when the valve was replaced by a standard non-inductive resistance. (The deflections were given the same sense by reversing the leads to the moving coil.) The sensitivity was such that resistances up to 0·25 MΩ could be measured with applied potentials of the order of 100 V (r.m.s.).

The accuracy of the method was verified by making a Fourier analysis of oscillograms of the anode current. An example taken under conditions differing only slightly from those stated in Fig. 2 is given in Fig. 4, the resistance value measured as above being almost identical with the value revealed by analysis. The error in employing a sinusoidal anode voltage is small for coils of reasonable power factor, as shown in the Appendix.

(4) EXPERIMENTAL RESULTS

The relation between the fundamental component of negative resistance and the r.m.s. value of the sinusoidal fluctuations of anode potential are shown in Fig. 5(*a*). The resistance is high for small amplitudes and reaches a minimum when the amplitude increases, and finally again becomes large and ultimately positive. If the rejector resistance of the tuned circuit is less than this minimum value then oscillation will not be maintained. Since the resistance is high for small amplitudes, it is only possible to start the oscillation by temporarily

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* D. A. Bell: *Journal I.E.E.*, 1935, vol. 76, p. 415; E. B. Moullin: *Wireless Engineer*, 1938, vol. 15, p. 371.

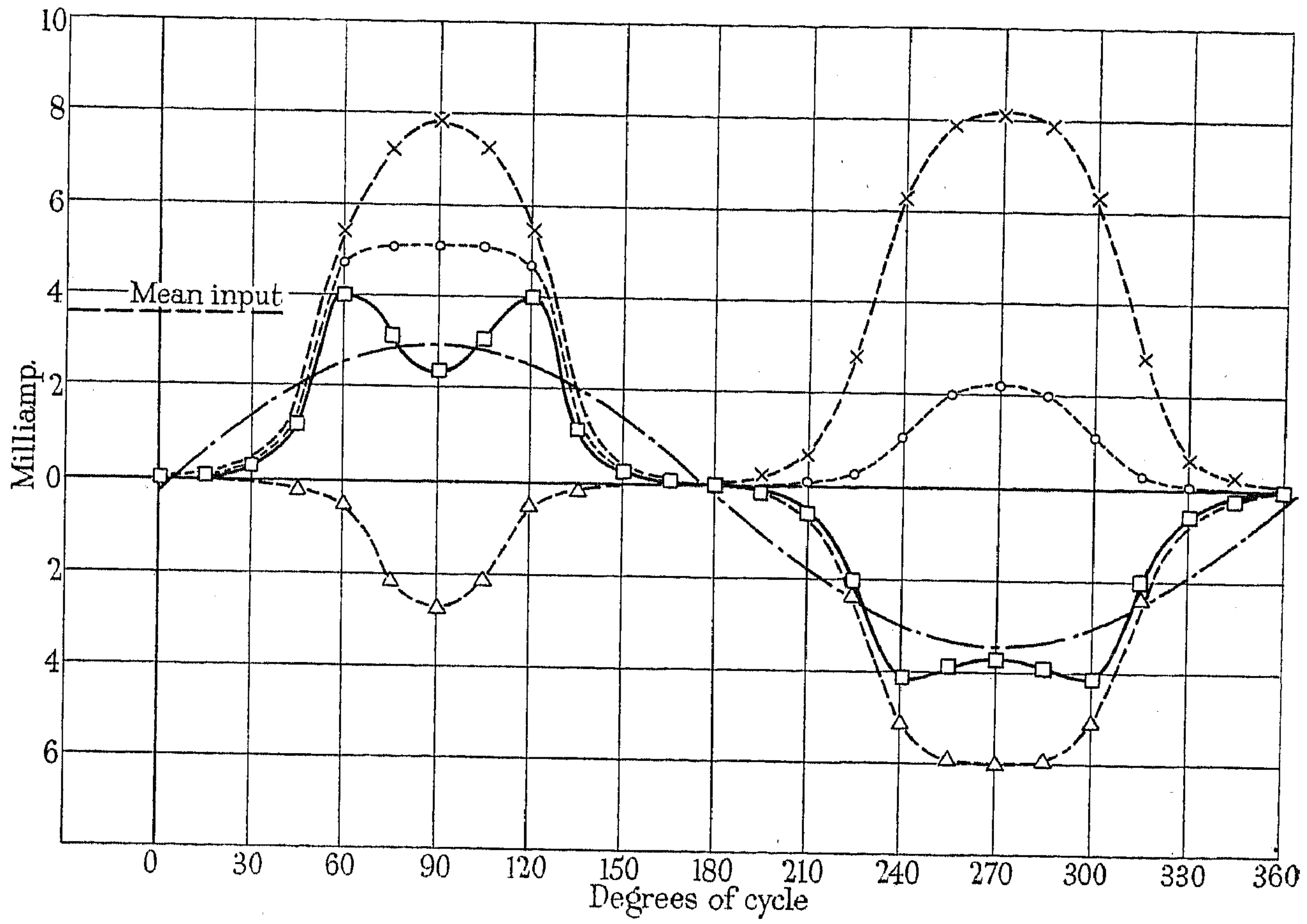

Fig. 2.—Cycle of currents deduced from Fig. 1:—

Anode 1 ○ - - - - - ○
Anode 2 △ - - - - △
Output ($A_1 - A_2$) □ ——— □
D.C. input ($A_1 + A_2$) × - - - - ×

Output (fundamental) —— · ——
Total a.c. voltage 110 (r.m.s.).
Field strength, 290 gauss.

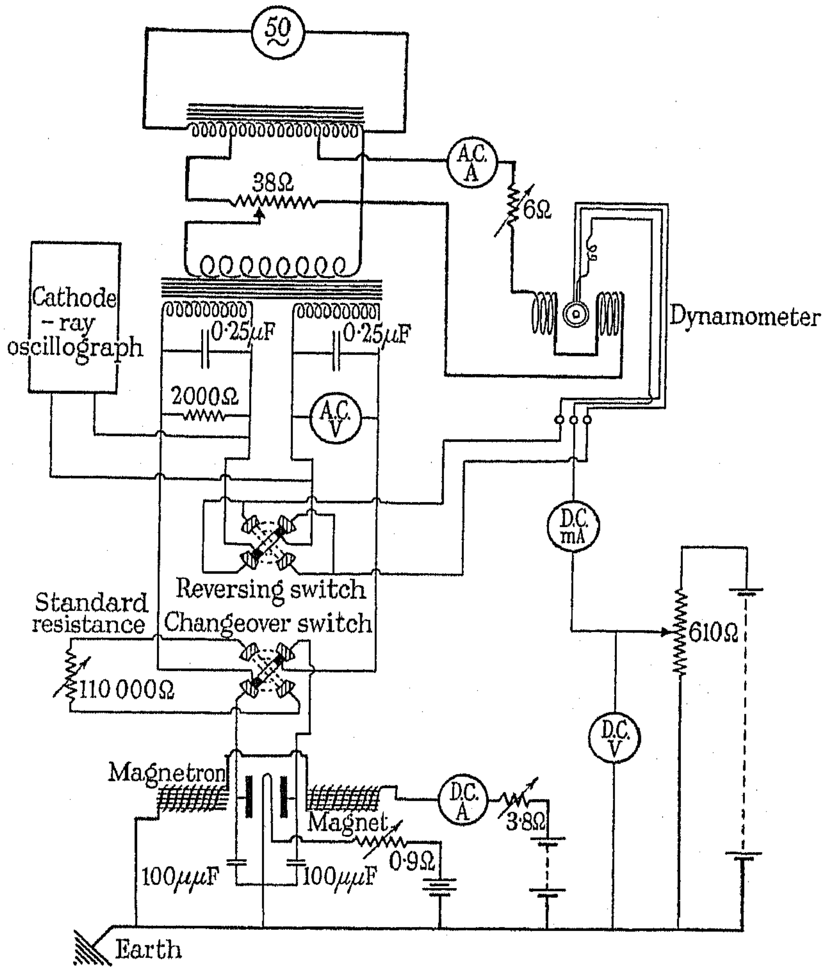

Fig. 3.—Diagram of connections used for measurement of magnetron impedance.

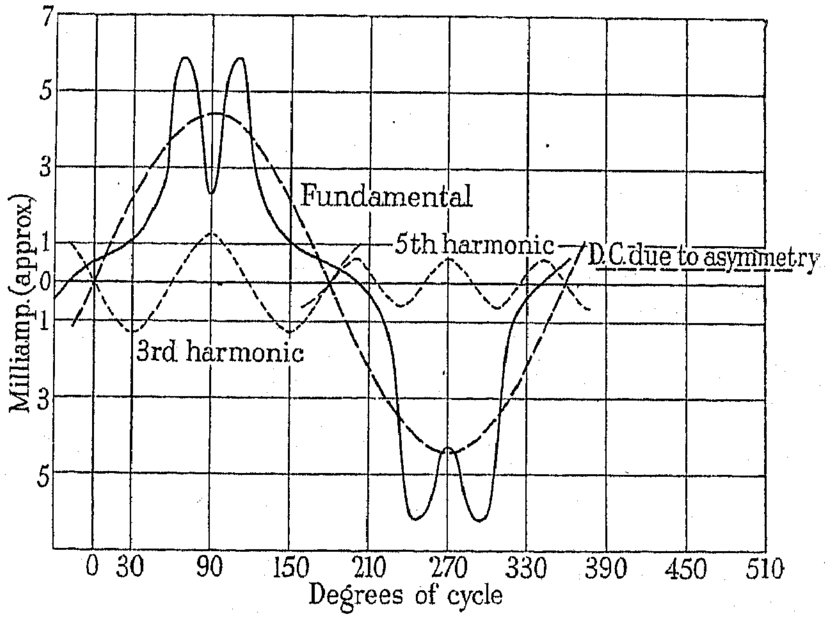

Fig. 4.—Wave-form of magnetron, deduced from oscillogram.

increasing the circuit resistance or reducing the magnetic field. For any circuit resistance higher than the minimum it is seen that two amplitudes are possible, the smaller one being unstable.

Ignoring the very small power dissipated in the circuit by the higher-harmonic components of current, the output would be V^2/R, where R is the negative resistance appropriate to the amplitude V. Fig. 5(b) shows this output; the curves rise to a maximum which occurs very near to the value of V giving minimum resistance.

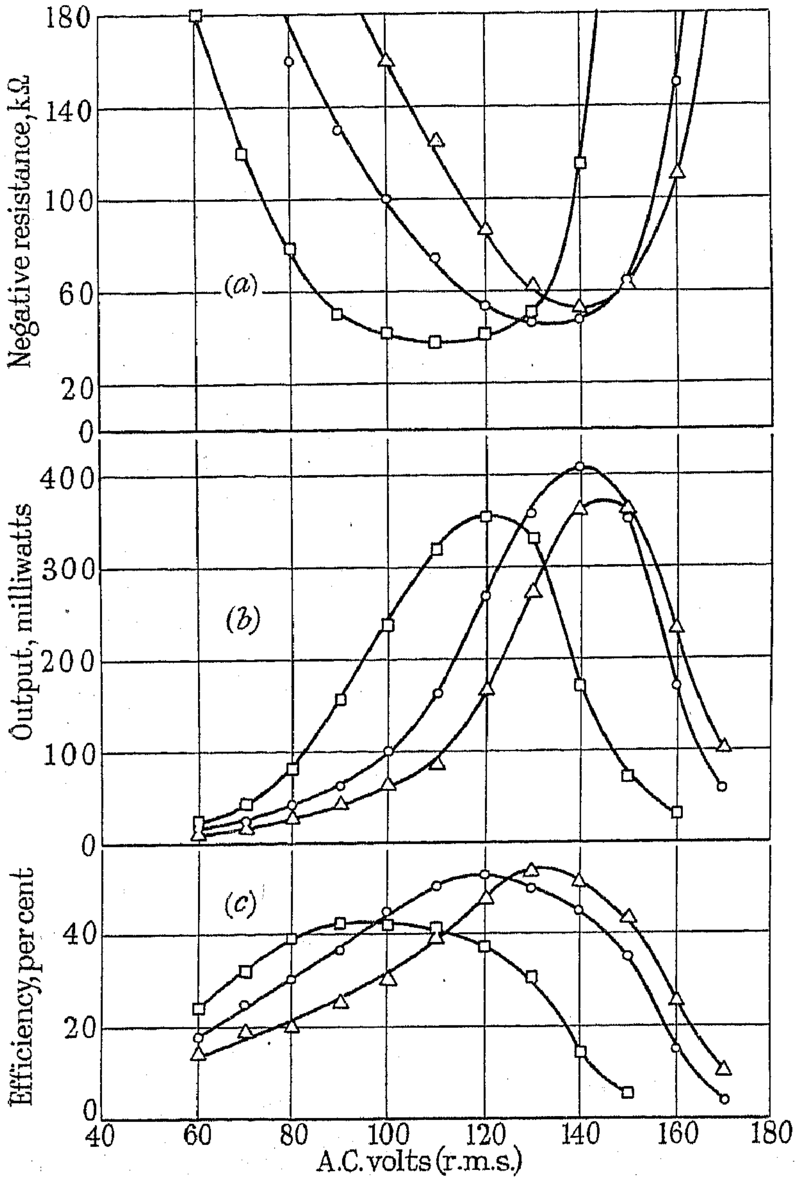

Fig. 5

Anode voltage 120
Filament emission 50mA
Field 220 gauss □———□
Field 290 gauss ○———○
Field 345 gauss △———△

In practice this optimum resistance value would be obtained by two tapping points on the coil. Measurement of the rectified anode current enables the efficiency to be calculated, and this is shown in Fig. 5(c). Comparison of these sets of curves shows that the amplitude for maximum efficiency is nearly that for maximum output and that there is a best value for the magnetic field which in general is about twice the critical field. These optimum conditions are examined below.

Fig. 6(a) shows the manner in which the load resistance for maximum output is related to the voltage of the H.T. supply, for different filament emissions. The field strength for maximum output increases in a nearly parabolic manner with anode voltage, as shown in Fig. 6(b), the effect of filament emission being small.

Figs. 7(a) and 7(b) show the relation between maximum output and efficiency, respectively, with supply voltage, and it will be seen that it is important to have as large a filament emission as possible. It was not possible to use supply voltages up to the maximum for this particular valve (1 000 V), but Fig. 8 gives a relation between output and supply voltage and filament emission which can be used as a guide. It is seen that this relation is best given by the equation

$$W = 0{\cdot}55 \times 10^{-4} \times V^{3/2} \times I^{1/2}$$

where W is in watts, V in volts, and I in mA.

(5a) EFFECT OF TILTING THE MAGNETIC FIELD

The previous experiments were made with the direction of the magnetic field coincident with the axis of the electrodes. Fig. 9(a) shows the effect on the output of inclining the electrode axis to the field. The upper and lower curves relate to a constant field strength, and show the relation between maximum output and angle of tilt: it may be seen that in these conditions the output may be increased or decreased by tilting the electrodes. These changes, however, are not due to adjustment of the axial component of the field strength as such (thus cos 6° = 0·9945), but are related to pronounced changes in the foot of the cut-off curve. The middle curve of Fig. 9(a) relates to a test in which the field strength was adjusted to give maximum output at various angles of tilt. Fig. 9(b) shows the corresponding curve of efficiency in the three conditions of test used in Fig. 9(a). The efficiency is small at large angles of tilt, because then the current cannot be cut off by the field in the static state. Examination of the wave-form of current showed that the harmonic content in certain cases was reduced slightly by tilting the field: this is probably associated with the small rise of efficiency and output.

(5b) MODULATION

The behaviour of the valve under conditions of anode modulation for use as a radio-telephone transmitter is given in Fig. 10 for a constant value of magnetic field and different circuit impedances. On the rising portion of the curve only a certain depth of modulation can be used without causing the oscillations to cease, but the linearity is good. The falling portion enables nearly full modulation to be obtained but the linearity is not good, the efficiency is poor due to the employment of high anode voltage at a comparatively low field strength, and, as will be seen below, considerable frequency modulation is present.

(5c) FREQUENCY STABILITY

In the absence of changes due to temperature, etc., in the values of the circuit parameters the frequency stability depends mainly on the harmonic content of the anode current, and the analysis given for the dynatron* can be applied to the magnetron directly.

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* E. B. Moullin: *Journal I.E.E.*, 1933, vol. 73, p. 186.

Some measurements (made at radio frequency as described later) are given in Fig. 11 (*a*, *b*, and *c*), the latter being of importance in showing the variation in carrier frequency under anode modulation. Provided the valve is operated near its best conditions the frequency changes as shown by the full lines are small, but become large when the conditions are such that the output is small and the current wave-form very distorted. Comparison with Fig. 10 shows that the value of anode voltage for maximum output corresponds to the position of minimum frequency.

(6) RADIO-FREQUENCY MEASUREMENTS

To check the validity of the method of predicting the performance in terms of the fundamental component of negative resistance appropriate to a sinusoidal fluctuation of anode voltage, the output was measured when the system was acting as a self-contained generator.

A frequency of about 200 kc./sec. was chosen because it was convenient for measurement, far removed from the conditions of tests at 50 cycles per sec. and also from the region of resonance oscillations. The circuit diagram is drawn in Fig. 12, which also shows the values of the various circuit components. It was necessary to connect the two anodes to the cathode by condensers of 100 $\mu\mu$F capacitance as shown, to prevent short-wave oscillations. The high-frequency resistance of the coil and condenser (when connected to the cold magnetron) was measured in the frequency range 170–290 kc./sec.: in this range the power factor was constant to within

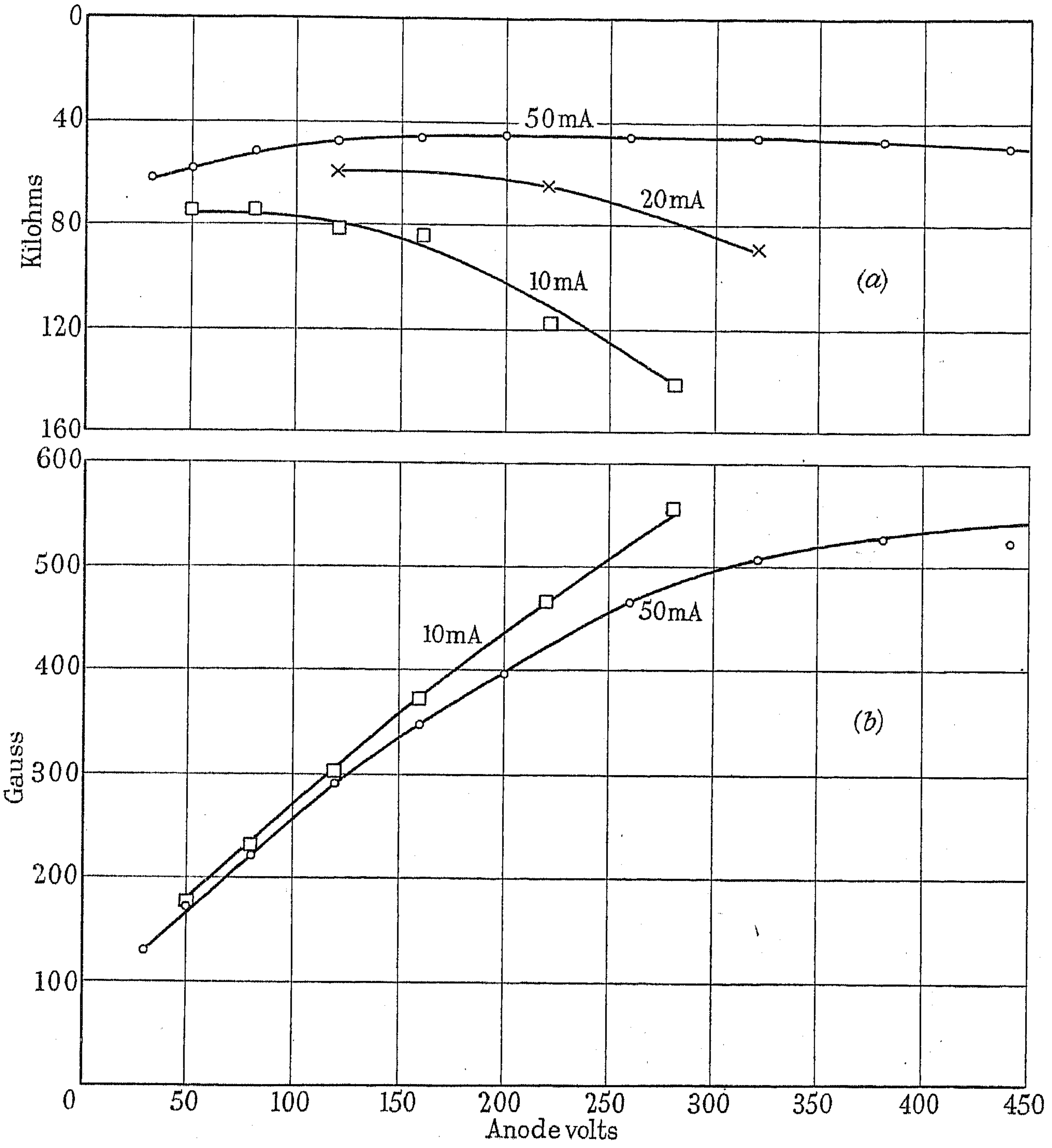

Fig. 6

(*a*) Variation of optimum load impedance with anode voltage.

Total filament emission 10 mA □——□
Total filament emission 50 mA ○——○
Total filament emission 20 mA ×——×

(*b*) Variation of optimum field strength with anode voltage.

Total filament emission 10 mA □——□
Total filament emission 50 mA ○——○

± 2 % and had a mean value of 0·6 % (i.e. $Q = 166$). The current through the condenser was measured by a thermal ammeter, or deduced from the reading of an electrostatic voltmeter when the resistance of the thermal ammeter (1·02 ohms) was objectionable. The load impedance was varied by means of a 10-ohm calibrated resistance box valid at 200 kc./sec.

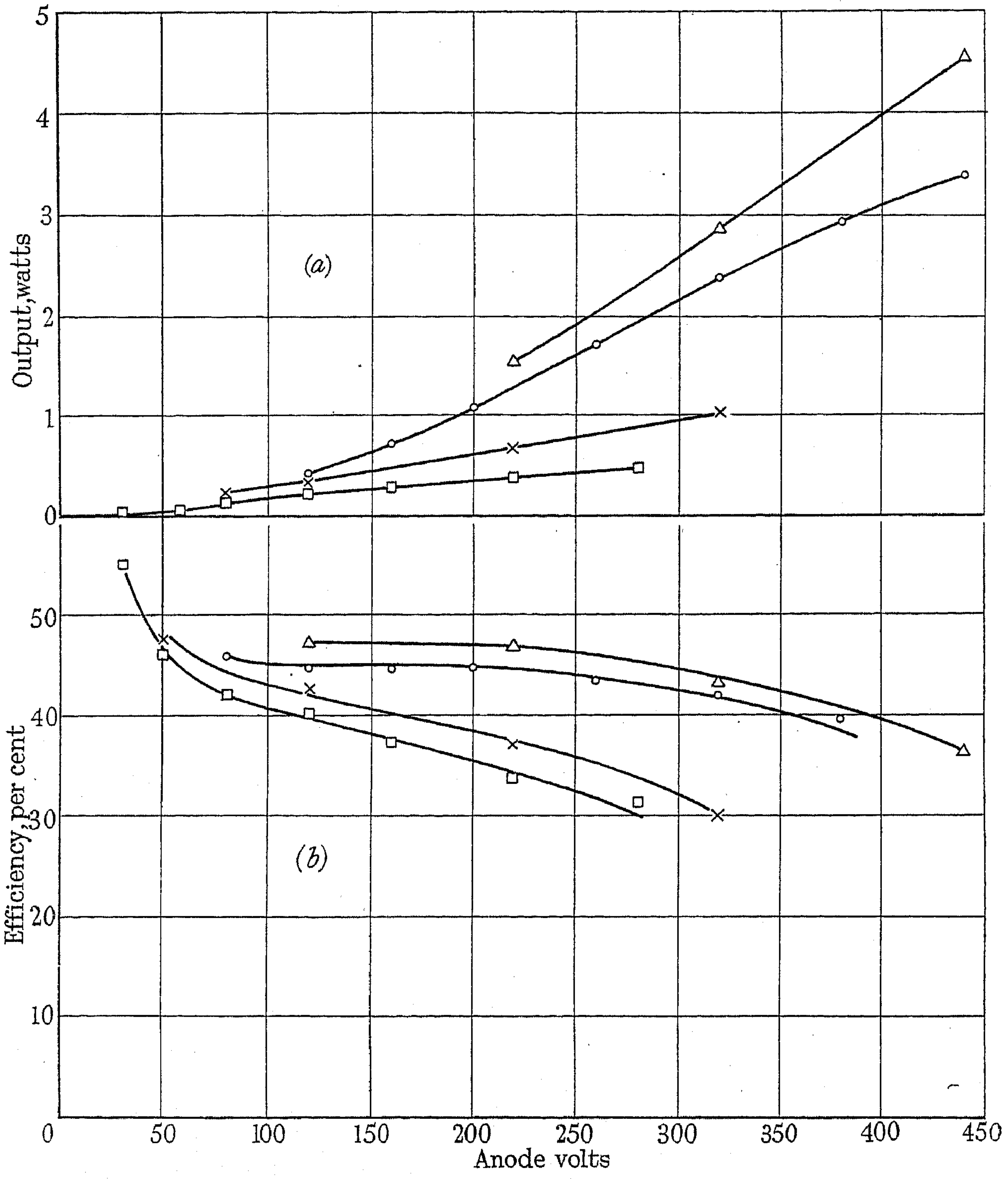

Fig. 7

(a) Variation of maximum output with anode voltage.
(b) Variation of efficiency at maximum output with anode voltage.

Total emission 80 mA △——△
Total emission 50 mA ○——○
Total emission 20 mA ×——×
Total emission 10 mA □——□

Measurements of output were made in a variety of operating conditions, shown collected in Tables 1 and 2. The last two columns of Table 1 show respectively the output in mW measured when oscillating at 200 kc./sec. and predicted from the tests at 50 cycles per sec. such as are recorded in Figs. 5, 6, etc., and the agreement is satisfactory. In Table 2 the ammeter and series resistance was removed and then the circuit had a rejector resistance of 63 kΩ. The output voltage was measured for various supply voltages, and the measured and predicted values are shown for comparison in the 6th and 7th columns of Table 2: here the agreement is usually closer than 1 % and well within the accuracy of measurement. The figures in the last two columns of Table 2 show for comparison the measured and predicted input;

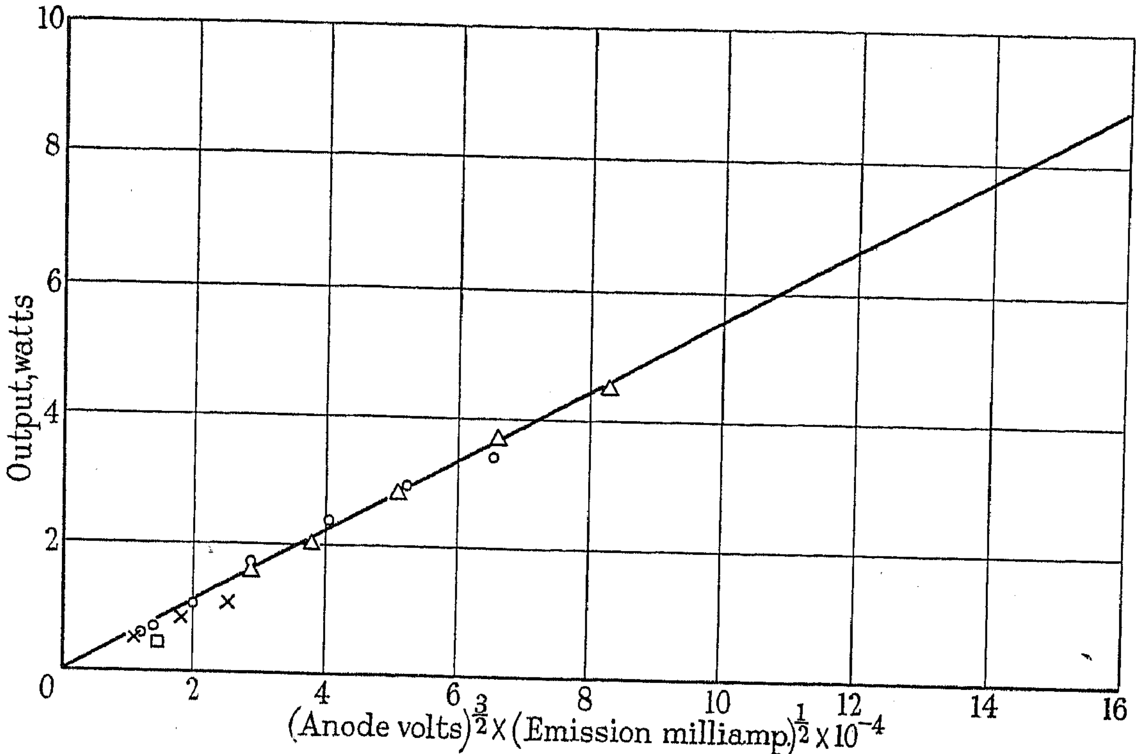

Fig. 8.—Variation of output with anode voltage and filament emission of magnetron.

Emission 80 mA △ Emission 50 mA ○ Emission 20 mA × Emission 10 mA □

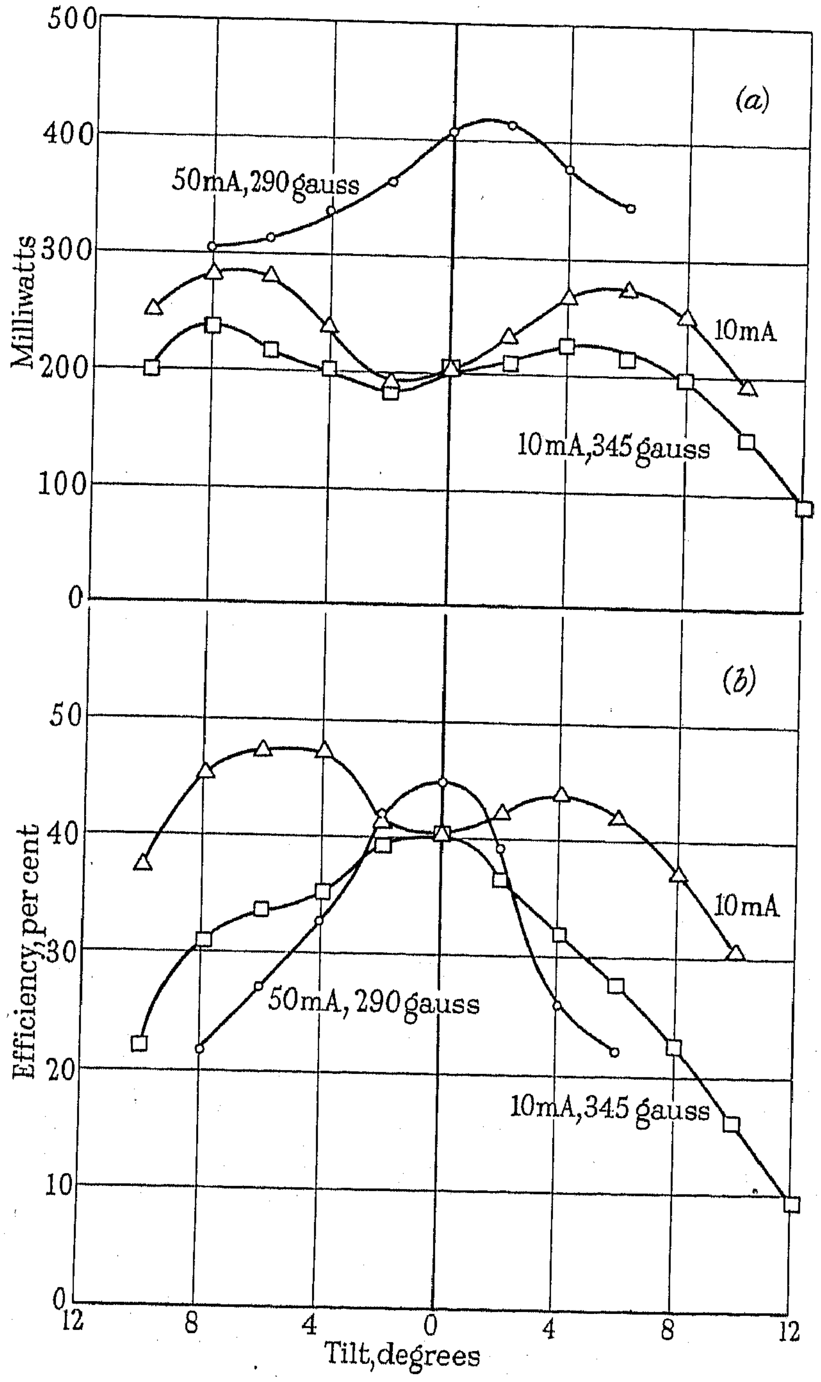

Fig. 9

(a) Variation of power output with tilt of field, at constant anode voltage (120) and saturation emission.
(b) Variation of efficiency with tilt of field, at constant anode voltage (120) and saturation emission.

With constant field and optimum load impedence ○——○
With constant field and optimum load impedence □——□
With optimum field and optimum load impedance △——△

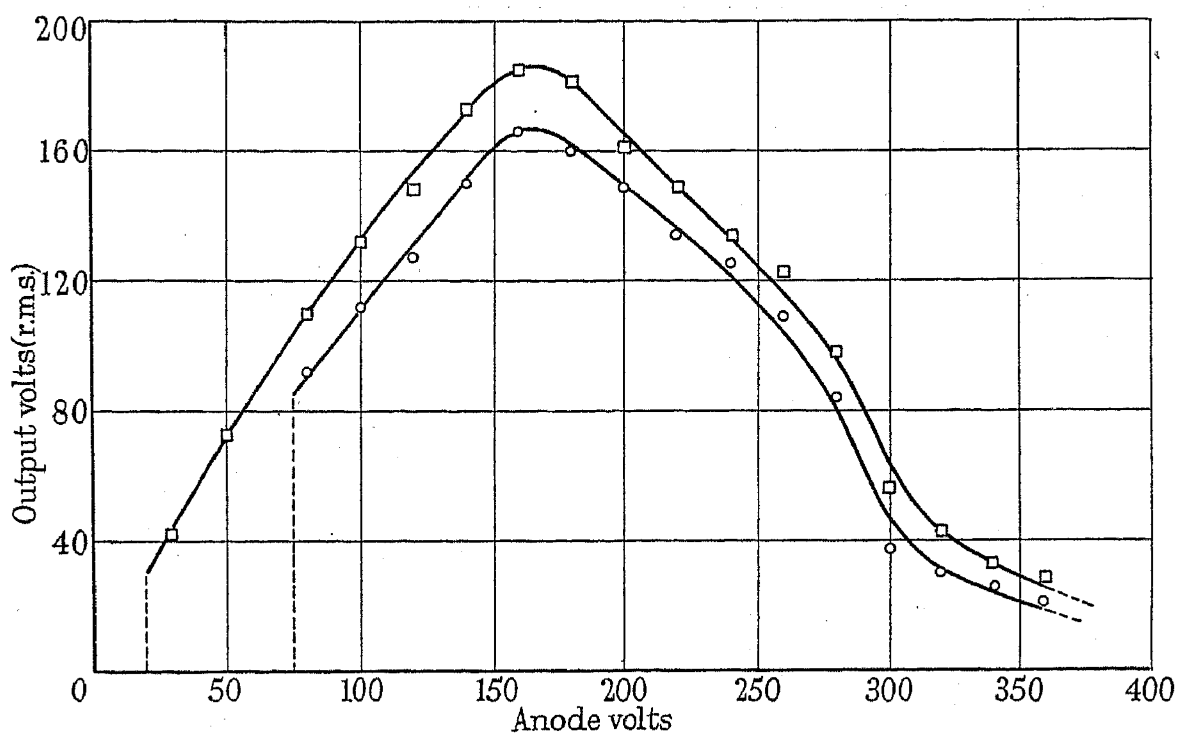

Fig. 10.—Variation of output voltage with anode voltage.

Field strength 230 gauss.
Filament emission 50 mA.
Load impedance 50 kΩ. ○——○
Load impedance 200 kΩ. □——□

Table 1

Anode volts	Field	Saturation emission	Angle of tilt	Series resistance	R.F. current	Output	Value at 50 cycles	Discrepancy
	gauss	mA		ohms	mA	mW	mW	%
220	230	50	0	6·19	286	508	526	+ 3·5
160	230	50	0	5·20	333	580	605	+ 4·3
140	230	50	0	4·20	307	398	438	+ 10
120	230	50	0	3·22	294	342	337	— 1·4
120	290	50	+ 5°	4·20	250	264	290	+ 10
120	255	50	0	3·22	303	296	282	— 4·7
120	255	80	0	3·22	307	304	310	+ 2·0

Table 2

Anode volts	Field	Saturation emission	Angle of tilt	Dynamic impedance	R.F. volts	Volts at 50 cycles	D.C. input	Input at 50 cycles
	gauss	mA		ohms			mA	mA
220	345	50	0	63 000	246	244	—	—
200	345	50	0	63 000	233	232	—	—
180	345	50	0	63 000	216	214	—	—
160	345	50	0	63 000	198	204	—	—
140	345	50	0	63 000	174	176	—	—
120	345	50	0	63 000	150	152	6·50	7·02
100	345	50	0	63 000	125	123	—	—
120	290	50	0	63 000	150	149	8·20	8·35
120	220	50	0	63 000	135	134	9·40	9·50

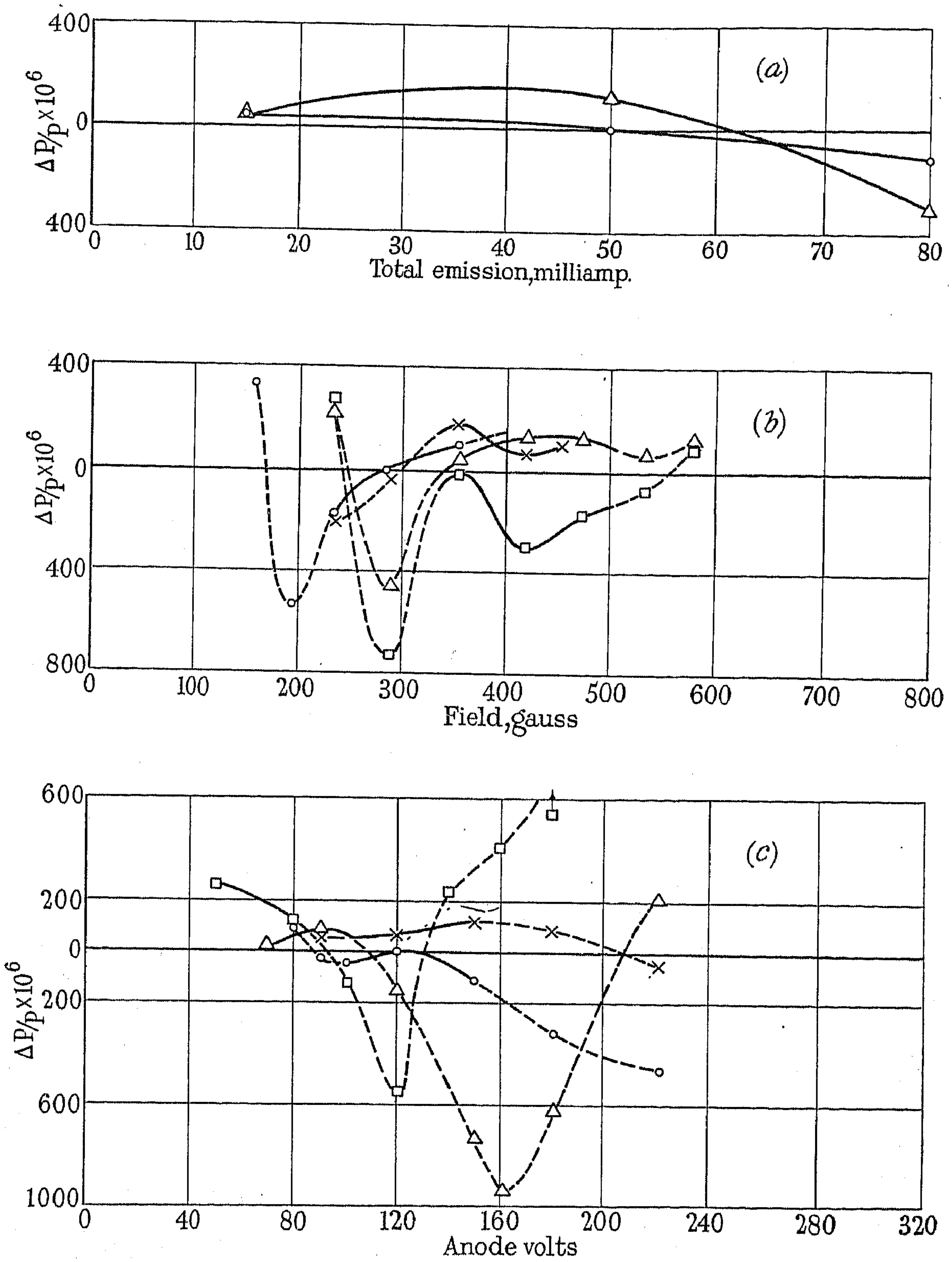

Fig. 11.—Variation of frequency with operating conditions. Mean frequency 200 kc./sec.; load impedance 63 kΩ.

(a) 220 volts, 420 gauss △——△
120 volts, 290 gauss ○——○

(b) 120 volts, 50 mA ○——○
220 volts, 50 mA △—— —△
220 volts, 15 mA ×——×
220 volts, 80 mA □——□

(c) 235 gauss, 50 mA △——△
290 gauss, 15 mA ×——×
290 gauss, 50 mA ○——○
195 gauss, 50 mA □——□

here again the agreement is satisfactory. Thus these measurements perhaps suffice to establish the validity of the method of prediction.

(7) CONCLUSION

The paper has demonstrated that the performance of the split-anode magnetron can be predicted with good accuracy by measurements at power frequencies made as described. The method is much more convenient than deduction from static curves, since to obtain information as to the best performance under various conditions a large number of curves would have been necessary and a Fourier analysis made in each case.

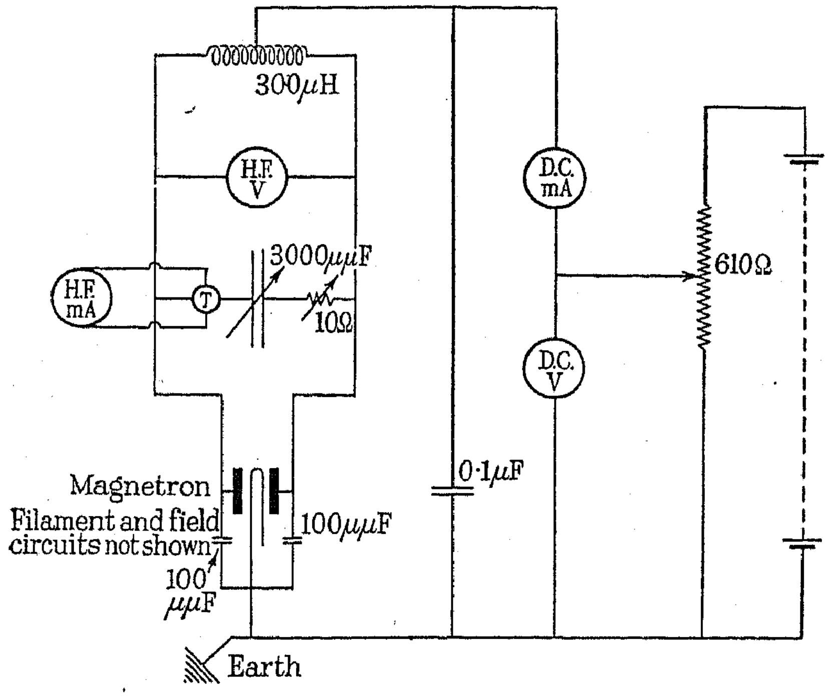

Fig. 12.—Diagram of connections for radio-frequency measurements.

The experimental curves given in the case of the particular valve enable the best operating conditions and circuit design to be chosen for any required output. In addition, they are capable of predicting accurately the performance at frequencies up to that at which electron transit time commences to play a part.

ACKNOWLEDGMENTS

The author's thanks are due to Mr. E. B. Moullin, M.A., Member, who has supervised the work, which was carried out in the Engineering Laboratory of the University of Oxford.

APPENDIX

The experiments recorded in this paper relate to simple-harmonic fluctuations of anode potential. This condition cannot obtain in a self-maintained generator since the resulting anode current is complex and must flow through the oscillatory circuit. However, the properties of this circuit are such that the harmonic components of voltage are much less than the corresponding components of current. Thus if V_1, V_3, V_5, etc., are the voltage components due to currents I_1, I_3, I_5, etc., flowing through a rejector circuit tuned to I_1 and having a power factor F, then it is well known that

$$\frac{V_3}{V_1} = \frac{3}{8} \cdot \frac{I_3}{I_1} F, \quad \frac{V_5}{V_1} = \frac{5}{24} \cdot \frac{I_5}{I_1} F, \quad \text{etc.}$$

Fourier analysis of the typical anode current represented by Fig. 4 shows that $I_3/I_1 = 0 \cdot 28$ and $I_5/I_1 = 0 \cdot 14$: hence it follows that if F is less than $0 \cdot 1$ no harmonic component of voltage is as great as 1 %. Hence it may be seen that the assumption of simple-harmonic voltage fluctuation is a very close approximation to the conditions obtaining in practice in a self-maintained generator. To examine whether the experimental results are sensitive to small changes in the wave-form of anode voltage the test corresponding to that recorded in Fig. 4 was performed with a peaked wave-form of voltage containing 3rd- and 5th-harmonic components of approximately 5 % and 3 % respectively. It was found that such change of wave-form resulted in the output being decreased by 11 %, from 409 to 363 mW. Thus it is clear that the method described for predicting the performance of a magnetron is sensibly correct even when the oscillatory circuit has a power factor much greater than would usually be tolerated in practice.

QUASI-STABLE FREQUENCY-DIVIDING CIRCUITS*

By R. L. FORTESCUE, M.A., Graduate.†

(*Paper first received* 1*st July, and in revised form* 25*th November*, 1938.)

SUMMARY

The paper describes some of the physical mechanism involved in frequency-division by valve circuits; requirements which must be satisfied for such division to occur without free self-oscillation being derived. A practical circuit for this purpose is developed from this theory, and the form in which it has actually been used described; together with the results of some experiments on stability carried out on dividers of this type. In conclusion, some more complex systems which might form subjects for future practical investigation are indicated schematically.

It is well known that an oscillatory system supplied with energy at frequency nf can be synchronized to oscillate at an exact sub-multiple frequency f, when f lies between certain frequency limits. Any oscillatory circuit synchronized in this way provides a frequency divider; and most practical demultiplying circuits, including the multivibrator, are of this type.

There are, however, disadvantages in the use of self-oscillatory circuits for frequency division, for under certain conditions they may fail to synchronize, and so produce an output which is not at the correct sub-multiple frequency. When this difficulty is serious, special circuits which can only oscillate in the synchronized state are of value. Because they do not show the self-oscillatory property associated with unstable systems, circuits of this type can be described as "quasi-stable," while the fact that they always synchronize requires the added qualification that they are "interlocked."

The first quasi-stable interlocked circuits are apparently those due to Sterky‡ and Longo.§ They are mainly of use for division by 2, and consist of back-coupled balanced modulator circuits. A number of more general circuits appear to exist, however, and it is proposed (*a*) to describe the physical requirements for quasi-stable division; (*b*) to trace the design of a practical divider using an interlocked quasi-stable circuit which has been used for division by 3, 4, 5, and 6; and (*c*) to indicate some other circuits of the same type which might provide useful and interesting subjects for research.

(*a*) Quasi-stable frequency-dividing circuits are only extreme cases of synchronized oscillators, and the principle of their physical operation can be derived from consideration of the simplified valve oscillator shown in Fig. 1.|| A 1 : 1 transformer with no leakage is assumed, and also a high-impedance valve (e.g. pentode), whose anode current, for practical load resistances, is independent of the anode voltage-swing. These simplifications, while not invalidating the physical argument, avoid obscuring the principles by subsidiary effects.

It is proposed to examine the effect of harmonics in the grid-voltage wave-form on the energy fed back by the valve, and its reaction winding L_2, to the oscillatory circuit L_1,C; and to show that the amplitude and phase of the fundamental term fed back in this way depend upon the amplitude and phase of these harmonics. The reaction can therefore be regarded as composed of two parts, (1) that due directly to the fundamental in the grid voltage, and (2) that produced as a result of harmonics in the grid voltage. A quasi-stable dividing system results from the absence of the first of these parts.

Consider a grid-voltage wave-form

$$v_g = v[\sin \omega t + k_n \sin (n\omega t + \phi_n)]$$

(taking only one harmonic, for simplicity)

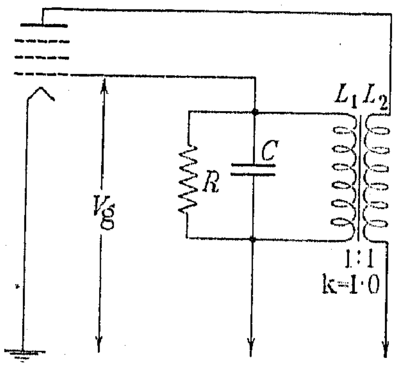

Fig. 1.—Simplified valve oscillator circuit.

The valve anode current, assumed independent of anode voltage-change, may be written

$$i_a = av_g + bv_g^2 + cv_g^3 + \ldots$$

Substituting the expression assumed for v_g, a Fourier series for i_a can be derived. The fundamental term of this series will consist of $av \sin \omega t$, plus a component from such products as

$$(v^{n-1} \sin^{n-1} \omega t)\,[vk_n \sin (n\omega t + \phi_n)]$$

which only appear in virtue of the presence of the harmonic in the grid circuit, and the non-linear terms in the valve characteristic.¶ An example, with second harmonic (i.e. $n = 2$), and valve with square-law characteristic, is given in Appendix 2 to show more exactly how this extra term arises. It is easily seen that harmonics

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† Formerly with the British Broadcasting Corporation.

‡ *Ericsson Technics*, vol. 2, p. 31; and *Proceedings of the Institute of Radio Engineers*, 1937, vol. 25, p. 1153.

§ *L'Onde Électrique*, 1934, vol. 13, p. 372.

|| See Appendix 1 for additional notes on physical theory involved.

¶ There will also be terms from the odd powers of v_g which do not involve harmonics; these limit the amplitude to which oscillations build up.

can "intermodulate" in this way between themselves as well as with the fundamental, and the general effect may be expressed by writing the fundamental term of the anode-current expression

$$I_0 = av \sin \omega t + f_1(v, a, b, \dots k_n, \dots \phi_n, \dots \text{etc.}) \sin \omega t \\ + f_2(v, a, b, \dots k_n, \dots \phi_n, \dots \text{etc.}) \cos \omega t$$

where $av \sin \omega t$ is the "linear" term which is used in simplified linear oscillator theory, and the rest is an added "intermodulation" term including a reactive component, arising from the non-linear valve characteristic which occurs in practice (and also from any harmonics which may be introduced into the circuit from external sources).

It is now clear that the magnitude and phase of the fundamental term of the reaction-coil current are, in part, dependent upon the harmonics in the grid circuit. In Fig. 1, when there is a steady maintained oscillation the grid voltage must be equal to the product of the L,C,R circuit impedance and the anode current. We have therefore an identity, at fundamental frequency,

$$v \sin \omega t \equiv Z\,[av \sin \omega t + f_1 \sin \omega t + f_2 \cos \omega t]$$

where f_1 and f_2 are the amplitudes of the intermodulation terms depending on the harmonics. For this identity to hold, the frequency must be such that the circuit L,C,R has a phase angle given by

$$\arc\tan \frac{-f_2}{av + f_1}$$

This is, in general, not zero, and the free frequency is therefore, in general, not that at which the circuit is resistive, $1/(2\pi\sqrt{LC})$; as would have been deduced by linear theory.

A practical oscillator, therefore, self-oscillates at a frequency shifted from its theoretical value as calculated by linear analysis. As this frequency-shift depends upon the harmonic intermodulation, introduction of an extra harmonic from an external source can vary it. Thus an oscillator which has a fundamental of 1 000 c./sec. when 3 000 c./sec. is injected from an external source in series with its grid, may have a frequency of, say, 1 200 c./sec. if this harmonic is removed; while its frequency calculated by linear analysis is

$$\frac{1}{2\pi\sqrt{LC}} = 1\,300 \text{ c./sec.}$$

This steady oscillation at a sub-multiple of an injected harmonic is the action which enables frequency-division to be obtained. For, in the case just considered, an oscillator of 1 200 c./sec. free oscillation *can** oscillate steadily at exactly a third of 3 000 c./sec. when this harmonic is injected into the circuit to "lock" it. The effect is due directly to the valve non-linearity and injected harmonic; and the greater the ratio of "intermodulation feedback" to "direct feedback," the more this injected harmonic can control the frequency of oscillation.

It now appears that the synchronization effect is not fundamentally dependent upon the presence of "direct feedback" at all, and, therefore, that if the "intermodulation feedback" is increased, when normal reaction is reduced, the total feedback can still be sufficient to maintain oscillation. If this process is taken far enough, the direct reaction becomes insufficient for self-oscillation in the absence of the injected harmonic, and a quasi-stable system is obtained.

The physical requirement for a quasi-stable circuit is, therefore, (*a*) a low direct feedback that is not sufficient to cause free self-oscillation, and (*b*) a sufficient feedback due to intermodulation with the injected harmonic, to maintain oscillation when such a harmonic is injected from an external source, in spite of this reduced direct reaction. A reduction of direct reaction without loss of "intermodulation" effect may be obtained in practical form either by using the balanced circuits of Serky and Longo or more generally by using frequency-discriminating circuits. A practical frequency-divider using the latter is shown in Fig. 2; its operation can now be considered, and it can be shown to be interlocked as well as quasi-stable.

(*b*) Commencing from the valve oscillator of Fig. 1, it is required to obtain a circuit with reduced relative amount of direct reaction compared with that due to intermodulation with injected energy. To achieve this, the relative amplitude of the intermodulating harmonics, compared with the fundamental, in the grid-voltage wave-form of the reacting valve must be increased. It is therefore necessary to separate this reaction valve from the main oscillatory L,C circuit, tuned to the fundamental, across which the wave-form is necessarily good. By using a valve under conditions favourable to non-linearity as a separating stage, a large relative amplitude of harmonics is obtained in its anode current, despite this essentially good wave-form of the grid voltage across the tuned circuit L,C. Further, by tuning the anode circuit of this separator stage to a selected harmonic, the voltage on the grid of the reacting valve at that harmonic frequency can be made considerably greater than the voltage at fundamental frequency. The circuit of Fig. 2 is then arrived at, and it represents the simplest form of quasi-stable divider.

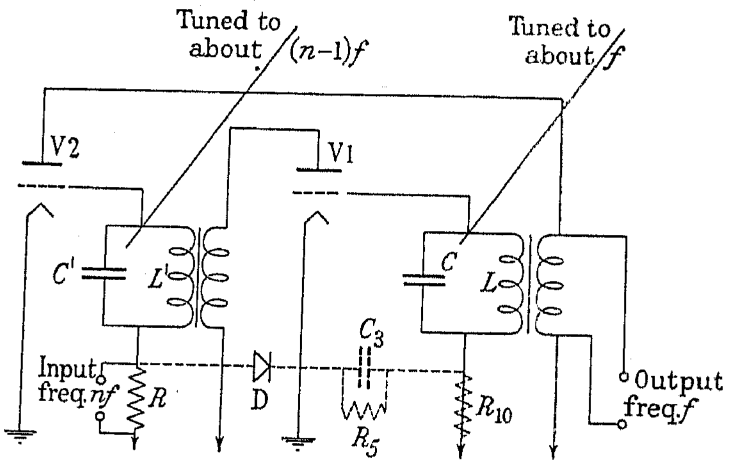

Fig. 2.—Simplified quasi-stable frequency-dividing circuit.

The operation of the circuit of Fig. 2 under working conditions can now be summarized:—

(1) The main oscillatory circuit L,C is tuned to about the required output frequency *f*. It is maintained in

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* See Appendix 3.

oscillation by means of the reaction coil in the anode circuit of V_2.

(2) The auxiliary circuit L′,C′ is tuned to a harmonic, $(n \pm 1)f$. When the main circuit L,C is oscillating at f, the separator valve V_1 acts as a harmonic generator and drives this auxiliary circuit L′,C′ at frequency $(n \pm 1)f$. V_1 also magnifies the fundamental of frequency f, but as the anode circuit is out of tune as far as this frequency is concerned, the circuit impedance is low and the magnification is very small; so that the voltage handed on to the grid of V_2 is almost entirely of the harmonic frequency $(n \pm 1)f$, at which the circuit is tuned.

(3) The resistance in the grid circuit of V_2, across the source of energy whose frequency is to be divided, results in this grid also being driven at frequency nf.

(4) The valve V_2, acting as a modulator with grid voltages at frequency nf and $(n \pm 1)f$, gives an anode current (which passes through the reaction coil) including the frequencies $nf \pm (n - 1)f$; which are the "sidebands" of nf when modulated with $(n \pm 1)f$. One of these terms is of frequency f, and the current component of this frequency in the reaction coil maintains the oscillation in the main circuit L,C when the loop gain is sufficient.

This action can only occur when the grid of V_2 is driven at frequency nf from the input; so the circuit is quasi-stable, direct reaction round the loop being avoided by the tuned circuits being sharply tuned to widely differing frequencies. The oscillation is also interlocked, for suppose it started at some frequency, different from the exact sub-multiple, $f(1 + \delta)$. The harmonic generator gives $(n \pm 1)f(1 + \delta)$, and the lower sideband when modulated with nf is :—

$$nf - (n \pm 1)(1 + \delta)f = \pm f(1 + \delta) - n\delta f$$

This is not of the same frequency as the original $f(1 + \delta)$, and therefore cannot maintain the oscillation.

Owing to the finite attenuation of the circuit L′,C′ at frequency f, and the circuit L,C at frequencies nf, $(n \pm 1)f$, direct reaction, though greatly reduced, is not completely eliminated, and it is found in practice that the remnant thereof should be arranged to be in correct sense (at least in simple circuits), to avoid increasing the apparent damping of the tuned circuits by negative reaction effect. Some care is also required in practice in adjusting the overall gain so that, while this remanent reaction does not cause self-oscillation, the intermodulation term is great enough to do so. The most satisfactory practical circuit actually tried is of the form shown in Fig. 3, where it is arranged for division by 3. The operation is identical with that just described with $n = 3$ and V_1 operating as a frequency doubler.

A fundamental difficulty arises in starting the oscillations in these circuits, on account of the output from the frequency multiplier V_1 (Fig. 2) of $(n \pm 1)$th harmonic being proportional to the $(n \pm 1)$th power of its input voltage, when this is small. The loop gain round the feedback path is therefore proportional to $v^{[(n \pm 1) - 1]}$, where v is the voltage across the main oscillatory circuit L,C. At the low levels of circuit noise, etc., which normally build up an oscillation, this gain may be less than unity, and therefore such building-up will not occur. The first experimental circuits of this kind were therefore started by whistling the required note into a microphone across the oscillatory circuit, which was interesting but laborious. A simple automatic form of starting circuit is shown in Figs. 2 and 3. The principle relies on the fact that by driving V_1 (Fig. 2), initially with frequency nf as well as f, it will act as a modulator and give, as sidebands, an output of $(n \pm 1)f$ as required [see (2) in col. 1], which is proportional to v instead of to $v^{(n \pm 1)}$. The loop gain is then independent of level, and circuit noise, etc., is sufficient to build up an oscillation. But because the system is not interlocked, although it is quasi-stable, such an oscillation is not necessarily synchronized. Once the amplitude of the starting oscillation has built up, however, V_1 gives enough gain as a harmonic generator to maintain the interlocked oscillation, and the extra drive on V_1 can be reduced until this interlocked oscillation is the only form possible. This "extra drive" is supplied across a resistance R_{10} in the grid circuit of V_1, as shown dotted in Fig. 2, and the condenser and leak arrangement C_3,R_3, charged by a rectifier D, gives a gradual reduction of the "starting voltage" on V_1 as the condenser charges up. The divider is thus made to interlock after a time determined by the product of C_3 and R_5, as well as being self-starting on application of input (provided that the input has been removed for long enough for

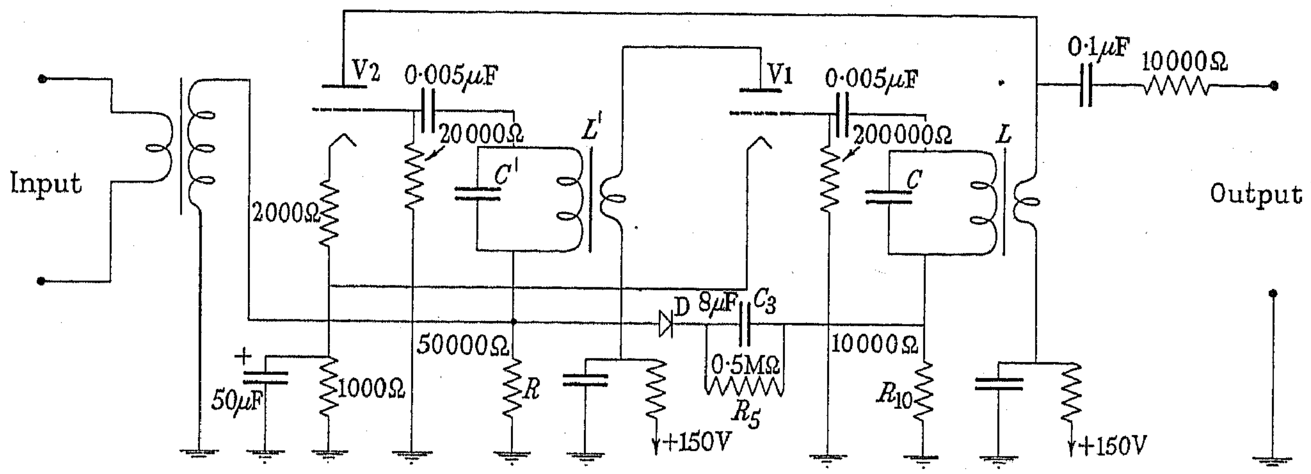


Fig. 3.—Practical quasi-stable circuit.

V and V_2 are Marconi H30 valves. L and L′ are dust-cored transformers with anode winding 8 mH and grid winding 130 mH. For division from 3 150 to 1 050 c./sec. the capacitances were $C = 0{\cdot}12\ \mu F$ and $C' = 0{\cdot}03\ \mu F$.

the condenser C_3 to discharge, a point which can be avoided, at the expense of some stability, by leaving some " residual " starting drive on V_1 at all times).

Owing to the use of tuned circuits, the operation of the divider of Fig. 3 is confined to a narrow frequency band near their resonant frequencies. The efficiency of the modulator stage V_2 depends also upon the input level of frequency $3f$ applied to it, no oscillation occurring if this is too high or too low. A range of levels and frequencies over which oscillation will occur is thus obtained, and a plot of this range is given in Fig. 4, for a particular divider with rather sharp tuning. The effect of variations of battery voltage is also shown, to give an indication of the improved stability of such a system compared with multivibrators or high L/C oscillators.

There are a variety of circuits of the quasi-stable interlocked type which appear to offer interesting possibilities for investigation. Fig. 5(*a*) shows a logical development of the circuit of Fig. 3, in which band-pass filters are used instead of simple tuned circuits. A preliminary and rather short experiment on this circuit indicated that the increase in frequency band was not as much as expected, however. Fig. 5(*b*) is the same circuit with high- and low-pass filters, while the arrangement of Fig. 5(*c*) shows a band elimination circuit. Starting provides something of a problem in these types on account of there being no sharply tuned circuit across which an oscillation can easily build up. It is also difficult in practice to obtain sufficient amplitude from a harmonic generator to maintain oscillation unless it is connected to a tuned circuit favouring the required harmonic.

Finally, Fig. 5(*d*) shows the first arrangement in its natural form for dividing by very high factors. An oscillator at nearly the correct frequency, 1 kc./sec., drives a succession of multipliers to give, say, 27 kc./sec. This output is fed, together with the input of 28 kc./sec., to a modulator. The output of this modulator is 1 kc./sec., and the auxiliary oscillator can now be faded slowly out, the oscillation being maintained by this 1 kc./sec. output from the modulator. Division by 28 should then be obtained without instability.

ACKNOWLEDGMENT

Acknowledgment is due to the British Broadcasting Corporation for permission to publish the paper, which is a result of work done in their Research Department.

APPENDIX 1

The physical description in terms of " reaction " here given is, of course, only one way of regarding the synchronization effect which occurs in all non-linear oscillatory systems. Amongst others, a point of view which has been found particularly useful is that of a valve which appears as a capacitance across the tuned circuit, thus retuning the oscillator to the synchronized frequency. The synchronizing effect is then due to the magnitude of this retuning capacitance varying with the phase angle between the synchronizing and synchronized oscillators. The effect has been studied experimentally in this form by connecting a valve showing " Miller effect " across an oscillator tuned circuit. The frequency of the oscillator can then be varied by adjusting the bias on this valve. By use of a rectifier this bias can be derived from the sum of the injected and local harmonics, and it will then depend upon their phase angle. Such a system has been observed synchronized, and in the process of synchronization, on the oscillograph.

The full mathematical theory (in general form), even for simple circuits, is very involved, van der Pol's approximations being the simplest method of approach. Conditions for the existence of a steady synchronized state (without reference to its stability; or transitional and unsynchronized forms) are in this paper approximated to by a more direct method. Suppose the circuit to be broken at some point, say at the grid of a valve, and assume the voltage across this grid to be given by the series

$$A_0 + A_1 \cos \omega t + B_1 \sin \omega t + \ldots$$

The voltages and currents at all other points in the circuit are then obtained in terms of A_0, A_1, etc., also as Fourier series in ω, the synchronized frequency. Finally, the voltage across the circuit which is actually connected to the grid is obtained as:—

$$\alpha_0 + \alpha_1 \cos \omega t + \beta_1 \sin \omega t + \ldots$$

where α_0, α_1, etc., are functions of A_0, A_1, etc., the circuit and valve constants, and the magnitude and phase of the " locking " input energy. Equating all the terms of the two series, a set of relations:—

$$\begin{aligned} A_0 &= \alpha_0, \\ A_1 &= \alpha_1, \\ B_1 &= \beta_1, \\ A_2 &= \alpha_2, \text{ etc.,} \end{aligned}$$

is obtained, and this must hold in practice when the circuit is connected to the grid. Where tuned circuits enable the Fourier series to be approximated to by one or two terms, this " loop " calculation is useful; also, it is exactly applicable to the question of stability at the origin when only the first terms are involved (Nyquist's criteria). In other cases, it is only of rather vague and general application, as the numerical solution of an infinite set of equations with an equal number of unknowns is not exactly practical. It may be noted, however, that whereas a " free " system has frequency ω but no phase angle ϕ_1 to be determined, a synchronized system having no unknown frequency ω will always have a determinate value for ϕ_1. That is, the phase of the synchronized oscillation relative to the synchronizing oscillation will be fixed and dependent upon the relation of synchronizing to free oscillation frequencies.

APPENDIX 2

Suppose the valve anode current is:—

$$i_a = av_g + bv_g^2$$

With sinoidal drive, $v \sin \omega t$,

$$\begin{aligned} i_a &= av \sin \omega t + bv^2 \sin^2 \omega t \\ &= av \sin \omega t + bv^2 \tfrac{1}{2}[1 - \cos 2\omega t] \\ &= \frac{bv^2}{2} + av \sin \omega t - \frac{bv^2}{2} \cos 2\omega t \end{aligned}$$

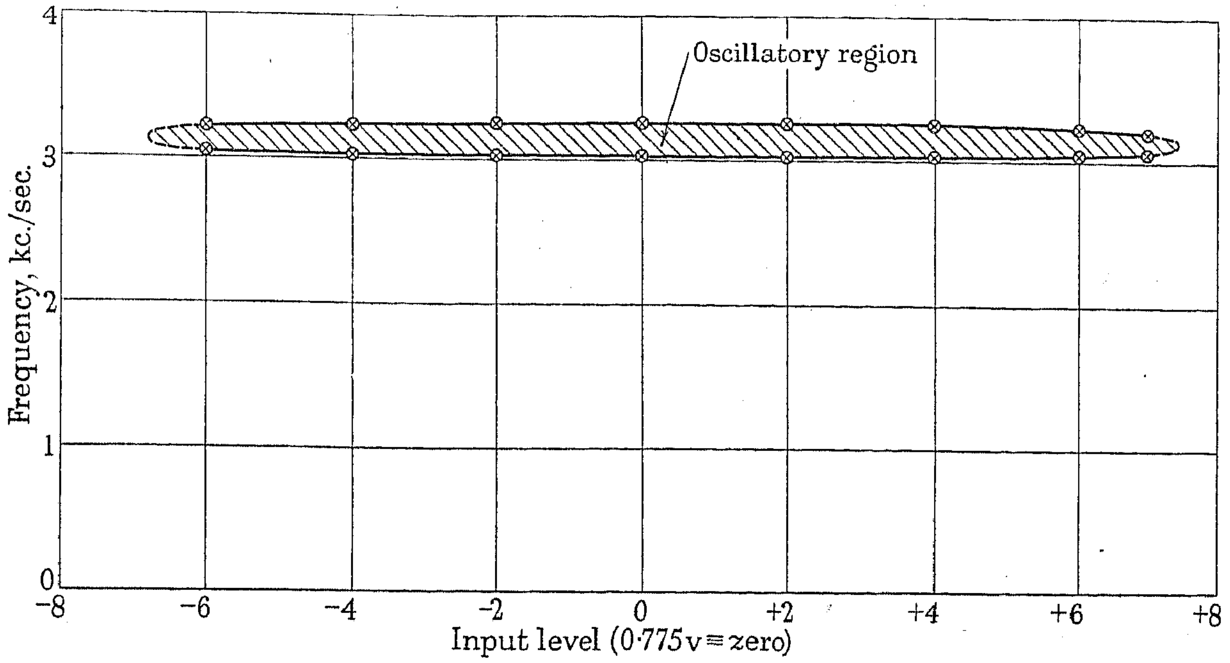


Fig. 4.—Experimental quasi-stable divider; test results.

Anode Currents at 150 V:—
With input $V_1 = 1 \cdot 8$ mA; $V_2 = 1 \cdot 2$ mA.
Without input $V_1 = 1 \cdot 2$ mA; $V_2 = 0 \cdot 3$ mA.

Frequency and level limits:—
150 V (H.T.) ± 3 % on 3 150 c./sec.; ± $\frac{7}{8}$db. on zero level.
165 V (H.T.) ± 3 % on 3 150 c./sec.; ± 8db. on zero level.
135 V (H.T.) ± 2·8 % on 3 150 c./sec.; ± $\frac{6}{8}$db. on zero level.

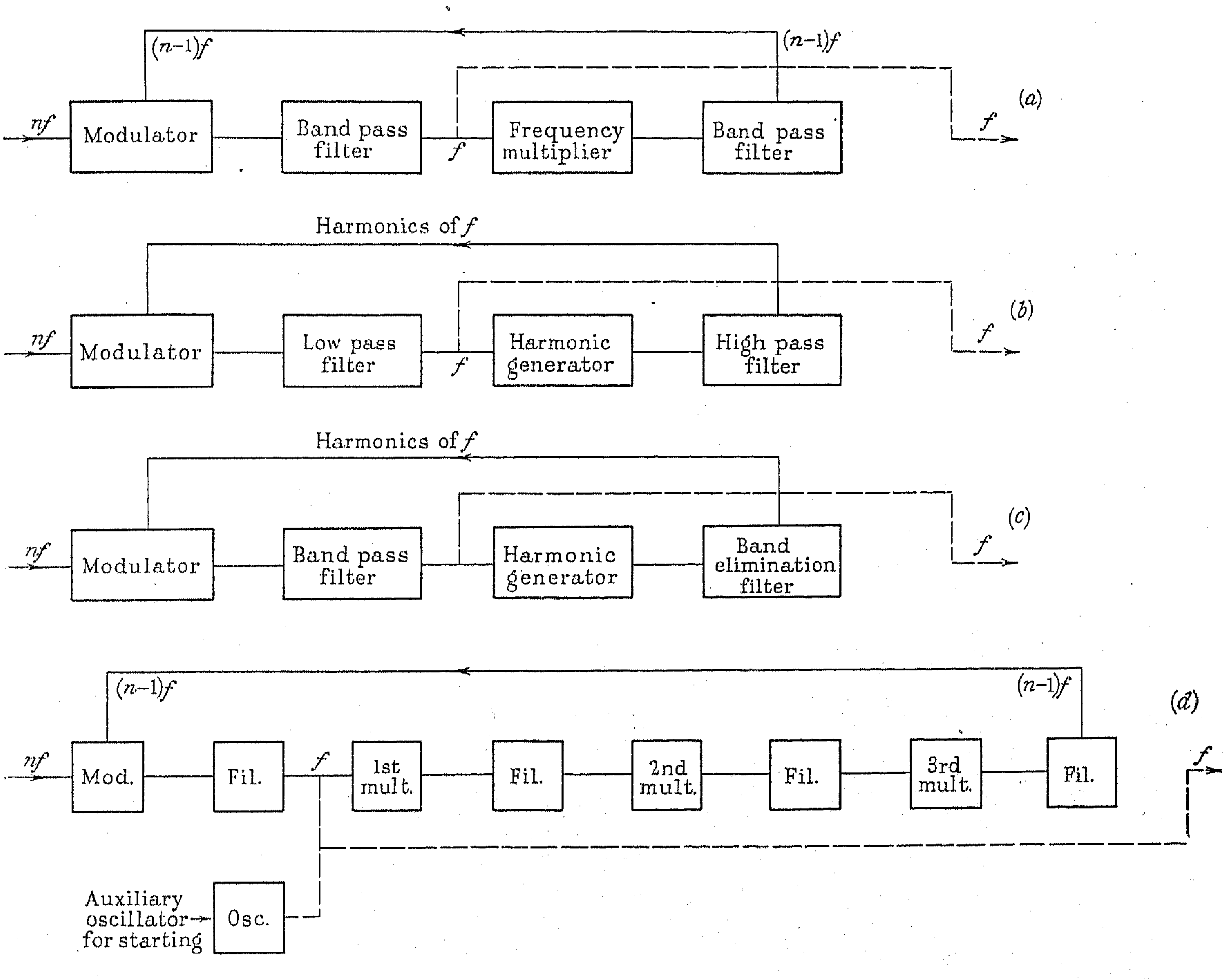


Fig. 5.—Possible developments from simple quasi-stable circuit.

The fundamental term fed back is ($av \sin \omega t$).

Adding 2nd harmonic $v_g = v[\sin \omega t + k \sin (2\omega t + \phi)]$

$$
\begin{aligned}
i_a &= av[\sin \omega t + k \sin (2\omega t + \phi)] + bv^2 [\sin^2 \omega t \\
&\quad + k^2 \sin^2 (2\omega t + \phi) + 2k \sin \omega t \sin (2\omega t + \phi)] \\
&= av[\sin \omega t + k \sin (2\omega t + \phi)] + bv^2\Big\{\tfrac{1}{2}(1 - \cos 2\omega t) \\
&\quad + \frac{k^2}{2}[1 - \cos (4\omega t + 2\phi)] + k[\cos (\omega t + \phi) \\
&\qquad - \cos (3\omega t + \phi)]\Big\} \\
&= \frac{bv^2}{2}[1 + k^2] + av \sin \omega t + bv^2 k \cos (\omega t + \phi) \\
&\quad + avk \sin (2\omega t + \phi) - \frac{bv^2}{2} \cos 2\omega t \\
&\qquad - kbv^2 \cos (3\omega t + \phi) - \frac{k^2 bv^2}{2} \cos (4\omega t + 2\phi)
\end{aligned}
$$

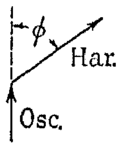
It will be seen that the fundamental term is now $av \sin \omega t + bv^2 k \cos (\omega t + \phi)$, the second term being introduced in virtue of the modulation product of $\sin \omega t \sin (2\omega t + \phi)$. Its phase depends upon the angle ϕ of the injected harmonic compared with the fundamental.

APPENDIX 3

It is shown in the analysis that an oscillator of free frequency ω_f may be able to maintain a steady oscillation at a different frequency, ω, if a harmonic of that frequency, $n\omega$, is injected. That it *will* do so, and continue, even if the harmonic frequency changes slightly, is a much more complex question. Suppose the input frequency changes to $n\omega(1 + \delta)$. It may be considered that the injected harmonic is still at the exact multiple, $n\omega$, but has changing phase angle, $n\omega\delta t$. As the phase of injected harmonic changes, however, the phase of the fundamental fed back changes, for the intermodulation feed-back depends upon harmonic phase relative to fundamental. As this change of phase of feed-back occurs, the frequency of the oscillator must change, and in a stable synchronized system this change of oscillator frequency to $\omega(1 + \delta')$ is such that the phase angle of the harmonic, which originally caused the change, is reduced. As this happens, the frequency changes back towards ω again; and a hunting, which must in practical cases be aperiodic, will occur until the system settles down with the fundamental and harmonics at some new angle giving just the correct sub-multiple frequency, $\omega(1 + \delta)$. The process can be described in terms of vectors:—

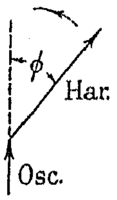
(1) Oscillation (multiplied by n) and injected harmonic; steady state.

Angle ϕ not changing, since system is synchronized.

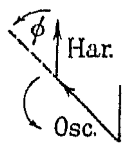


(2) Injected harmonic frequency increased, harmonic vector rotating and ϕ decreasing.

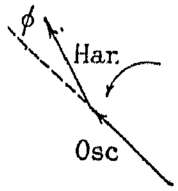
Decreased ϕ, however, increasing oscillator frequency.



(3) Oscillator frequency increased, "oscillation" vector therefore also rotating and "chasing" harmonic; rate of increase of ϕ falling.



(4) New steady state, reduced ϕ giving change of oscillation frequency equal to change of harmonic frequency, and whole diagram rotating with fixed angle between vectors. Rate of rotation equal to frequency change; rate of change of ϕ zero.



Practical synchronization requires, therefore, besides the "existence" condition given, an additional "stability" condition that, when small frequency-changes are made, the oscillator will follow them as described above. The process has been observed, with a special oscillator, on the oscillograph (see Appendix 1).

LOCALIZATION OF FLASHING FAULTS IN CABLES*

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(*Paper received 9th December*, 1938.)

SUMMARY

A method is given for localizing cable faults which flash over at a high voltage and heal at lower voltages. A new meter, which is used in the method described, and the auxiliary apparatus, are outlined briefly. The method of calculating the position of the fault is given in detail, and a correction factor is found semi-empirically to allow for the effect of the line. The theory of the discharge phenomenon is considered, and some experiments made under controlled conditions to check the theory provide oscillograph illustrations.

CONTENTS

(1) Introduction.
(2) The Method.
(3) Applications and Analysis of Results.
(4) Apparatus.
  (*a*) Test set.
  (*b*) Ballistic meter.
  (*c*) Operation.
(5) Theory of the Phenomenon.
  (*a*) The discharge current.
  (*b*) The deflection of the ballistic meter.
  (*c*) Correction factor.
(6) Oscillographic Tests.
  (*a*) Verification of V^2l law.
  (*b*) Form of the discharge current.

(1) INTRODUCTION

The modern practice of interconnection of large-power, high-voltage systems as exemplified by the grid scheme demands, above all things, the maximum reliability of operation. The primary burden in the achievement of reliability falls naturally upon the schemes of discriminative protection, which see to it that only the faulty sections of the system are switched out and the healthy sections are kept in to continue the supply. A secondary burden is well undertaken by the method of high-pressure, direct-current testing of cables. This is a sound preventive measure which diagnoses weaknesses before they become harmful, and is clearly conducive to higher reliability.

One of the main advantages of an interconnected system is that spare plant is reduced to a minimum. This advantage would be impaired if the localization of faults could not be performed quickly, in order to allow the faulty parts to be removed and the line to be made serviceable quickly. The authors will therefore consider briefly the faults that sometimes occur in power cables and joints and discuss their localization.

Of such faults as occasionally occur in power cables and their joints the following are the most common:—

(1) A fault between two conductors (mainly in unscreened cables).

(2) An earth on one phase (in cables or joints).

(3) Fault between two or more conductors, accompanied by earth faults (in cables or joints).

(4) A break in a conductor with high resistance to earth (in cables or joints).

(5) A break in a conductor, accompanied by a low resistance to earth (mostly in cables).

(6) A fault which is apparent only at high voltage and heals at low voltage (mostly in joints, but occasionally in cables). This type may easily be encountered in a high-pressure, direct-current test.

The positions of faults of the types (1) to (5) can be found by well-known methods.§ Faults of types (1) and (2) are found by the Murray loop test, (3) by the Werren overlap test, (4) by a capacitance method using a ballistic or a.c. method, and (5) by an a.c. inductance bridge method.

There remains to find the position of a fault, which flashes over at high voltage but heals at low voltage. In practice the breakers sometimes trip and yet an insulation test fails to indicate a fault. On reconnecting the supply the cable may function satisfactorily for a while and then the breakers may trip again. The Murray loop test and the other common methods cannot be used and it is the purpose of this paper to describe and explain a method of localizing such a fault and to give examples of use. The method is rapid and accurate, whereas the method hitherto used consisted of an attempt to break down the fault completely so as to use the Murray loop test, and took several days on some occasions.

(2) THE METHOD

Fig. 1 shows the schematic of the method. AB is a healthy single-core cable and CD a single-core cable with a flashing fault at P. The sheaths of the cables are earthed throughout their lengths and bonded at each joint. A is connected by a thick copper strap through a very low-impedance ballistic meter (G_1) to C, and B is similarly connected to D via G_2.

The conductors of the two cables are slowly charged up to a negative potential by a step-up transformer, rectifier, and limiting resistance. When the potential of the conductors reaches a certain value, depending on the fault at P, a flashover occurs and the meters G_1 and G_2 give deflections d_1 and d_2, say. The conductors are then slowly recharged and another flashover occurs.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† Marconi's Wireless Telegraph Company, Ltd.

‡ Callender's Cable and Construction Company, Ltd.

§ J. URMSTON: "Electrical High-Pressure Testing of Cables and the Localization of Faults," *Journal I.E.E.*, 1931, vol. 69, p. 983.

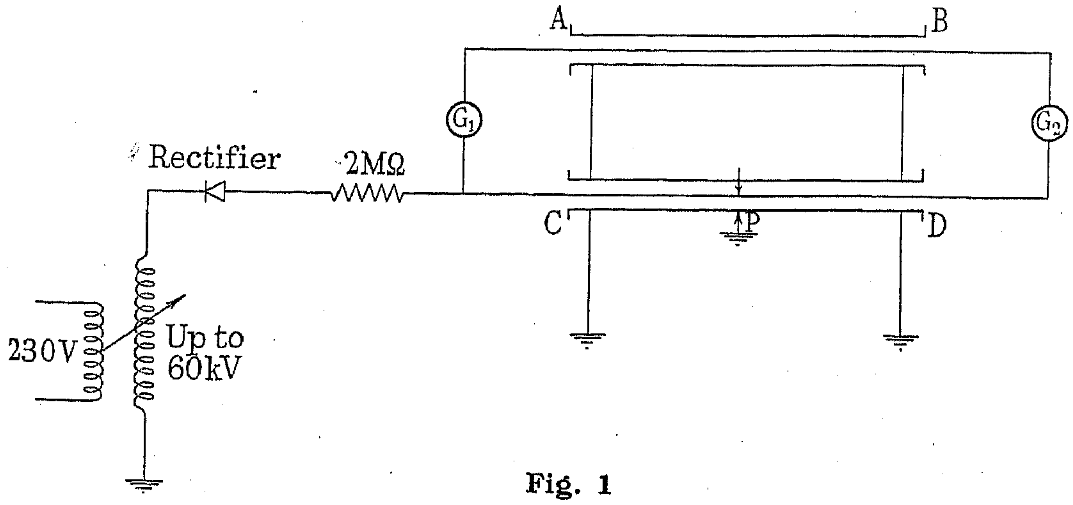

Fig. 1

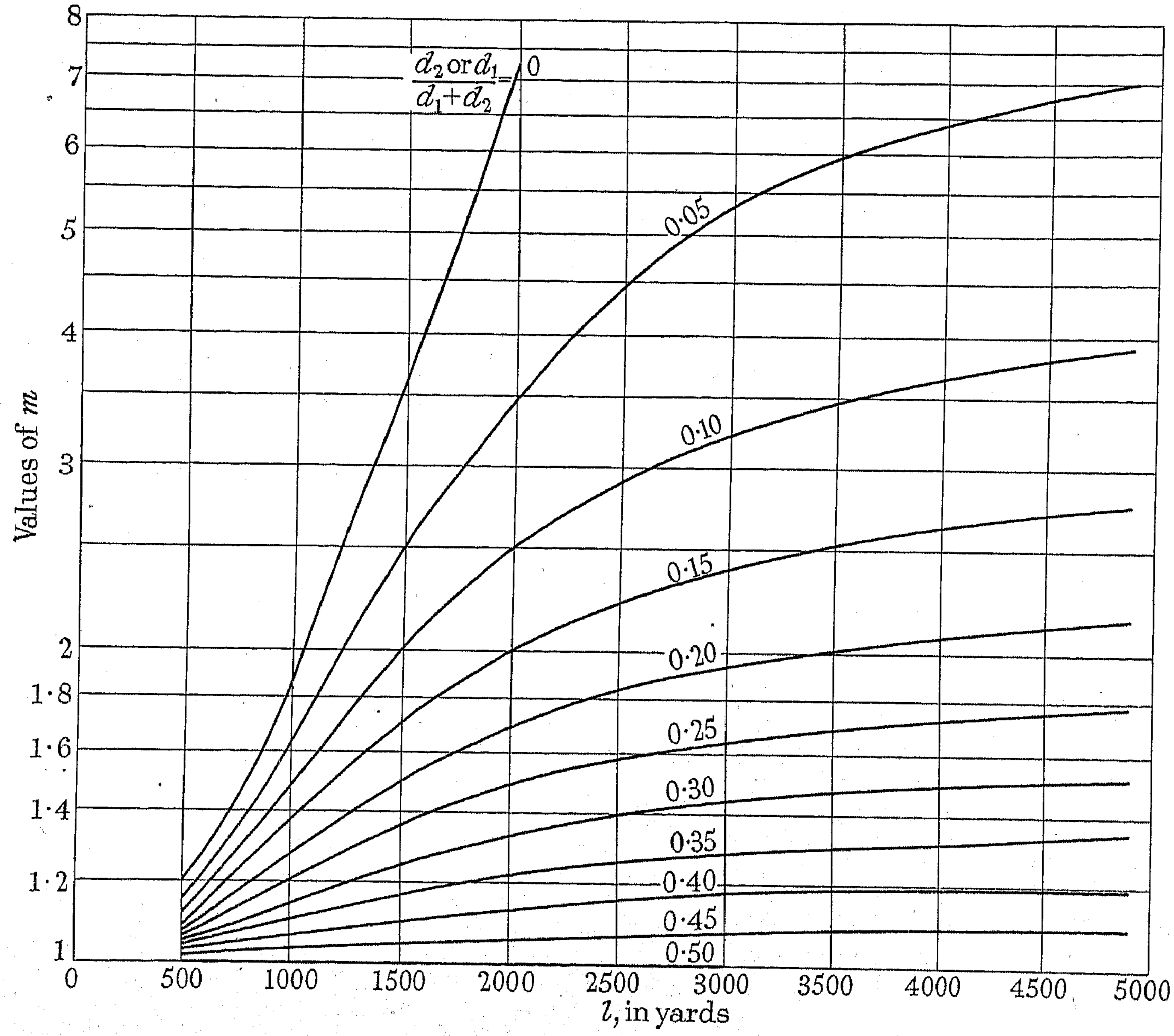

Fig. 2

Succeeding flashovers afford check readings. From the readings d_1 and d_2 and the route length of the cables, the position of the flashing fault P can be calculated by the equation:—

$$\mathrm{CP} = \frac{d_2}{d_1 + d_2} \times \mathrm{CD}$$

This theoretical formula is accurate when the discharge waves suffer no distortion or attenuation, and test measurements have verified it for a short length of travel (see Section 6). In practical cases, however, attenuation and distortion modify the readings d_1 and d_2 so that the formula is incorrect. A correcting factor m has been found by theory and based on tests, so that we can write:—

$$\mathrm{CP} = m \times \frac{d_2}{d_1 + d_2} \times \mathrm{CD} \quad . \quad . \quad . \quad (1)$$

where m depends upon the route length CD and the ratio $d_2/(d_1 + d_2)$. Fig. 2 gives m for the cases when P is nearer to C than to D.

When the fault is nearer to D than to C we have:—

$$\mathrm{DP} = m \times \frac{d_1}{d_1 + d_2} \times \mathrm{CD} \quad . \quad . \quad . \quad (2)$$

m now depending on $\dfrac{d_1}{d_1 + d_2}$

The values of m are given in Fig. 2. When P is nearer to C than D, d_2 is smaller than d_1, and the value of m is found from $d_2/(d_1 + d_2)$ and applied in equation (1).

As the sensitivity of the galvanometer required for this kind of work varies very much with small variations of manufacture, it has not yet been possible to produce two meters with identical sensitivities throughout their ranges. The same meter is therefore used at both ends of the cables. When the meter is connected between A and C, the conductors are bonded at B and D by a copper strap; conversely, when the meter is connected between B and D the conductors are bonded at A and C.

Table 1

Cable	Test at C		Test at D		$\frac{d_2}{d_1 + d_2}$	m	x (yd.)	Actual distance (yd.)
	kV	d_1	kV	d_2				
2 633 yd. of 3-core, 0·10 sq. in., 11 kV	30	15–19 17 average	30	6	0·261	1·56	1 060	980
4 624 yd. of 3-core, 0·15 sq. in., 11 kV	30 32	16 20 (17·6)	30 30 32 32	12 12 15 (13·2) 13 (11·4)				
Readings referred to 30 kV	Average (30)	16·8	(30)	12·1	0·418	1·12	2 160	1 973
766 yd. of 3-core, 0·25 sq. in., 11 kV	15 15 15 15 15	6 6 7 8 7	14 14·4 13·0 13·6 13·6	2 (2·14) 3 (3·12) 2 (2·3) 3 (3·3) 3 (3·3)				
Readings referred to 15 kV	Average (15)	6·8	(15)	2·8	0·292	1·10	246	304
1 075 yd. of 3-core, 0·25 sq. in., 11 kV	9·8 9·8 9·8	2·0 2·0 2·0	10 10 10	1·0 1·0 1·0				
Readings referred to 10 kV	Average (10)	2·08	(10)	1·0	0·326	1·13	396	419
5 513 yd. of 3-core, 0·20 sq. in., 22 kV	38 36 37 37 38 38·5	48 (53) 41 (50·7) 42 (49) 45 (52·5) 46 (51) 45 (48·5)	40 40 40 37 39 37	42 (42) 45 (45) 45 (45) 37 (43·2) 41 (43·2) 37 (43·2)				
Readings referred to 40 kV	Average (40)	50·8	(40)	43·6	0·462	1·05	2 680	2 543
4 717 yd. of 3-core, 0·20 sq. in., 33 kV	34 (41)	64 93	41 (41)	50 50	0·350	1·28	2 140	1 570
1 047 yd. of 3-core, 11 kV	19	31	19	2·5	0·075	1·6	126	170
2 292 yd. of 3-core, 0·3 sq. in., 11 kV	11	13	11	3	0·188	1·84	790	710
867 yd. of 3-core, 0·35 sq. in., 33 kV	28	14·7	28	2·57	0·149	1·28	165	170

The tests with the meter at one end will often require a different flashover voltage from the tests with the meter at the other end. The variations of flashing voltage are due to variations of the conditions at the fault. Later voltages may be higher than earlier voltages, owing to the increase of gas pressure at the fault caused by earlier flashes. It is thus necessary to allow for the variation of flashover voltage and it is shown later that, if the deflection d_1 occurs at voltage V_1, and d_2 at V_2, the value of d_2 in formulae (1) and (2) must be replaced by

$$d_2' = d_2\left(\frac{V_1}{V_2}\right)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

This formula also has been verified exactly by experimental tests under controlled conditions (see Section 6).

The method and formulae given above can be applied to 3-core cables, provided there is one sound core to take the place of AB. In such cases the third conductor is earthed.

(3) APPLICATIONS AND ANALYSIS OF RESULTS

Table 1 gives a summary of a number of localizations. When the voltages vary, the readings are reduced to a common voltage by means of equation (3) and averages are taken.

The localizations are fairly close with the exception of the sixth test. It is thought that the error in this case may be due to the fact that the instrument during this test was unscreened and the voltage was high, so that the ring did not stay at its zero position just before each flash. It will be seen later that the zero position is very critical.

In the last test case many readings were obtained; the full list is given in Table 2.

(4) APPARATUS

The apparatus comprises a portable high-voltage d.c. test set and a ballistic type of meter.

Table 2

kV	d_1	d_1 reduced to 28 kV
Test at C.		
28·0	14·0	14·0
28·5	16·0	15·2
28·0	15·0	15·0
29·0	15·5	14·5
28·5	15·5	15·0
29·0	16·0	15·0
29·0	16·0	15·0
27·0	13·0	14·0
28·0	15·5	15·5
28·0	14·5	14·5
28·5	16·0	15·2
29·0	15·0	14·0
27·5	14·5	15·0
28·0	15·0	15·0
29·5	17·5	15·0
29·5	17·5	15·0
27·0	12·0	13·0
29·5	15·5	14·0
29·5	17·5	14·8
	Average ..	14·7
Test at D.		
29·0	2·5	2·34
28·0	2·5	2·5
29·5	3·0	2·80
28·0	2·5	2·5
30	3·0	2·60
27	2·5	2·70
	Average ..	2·57

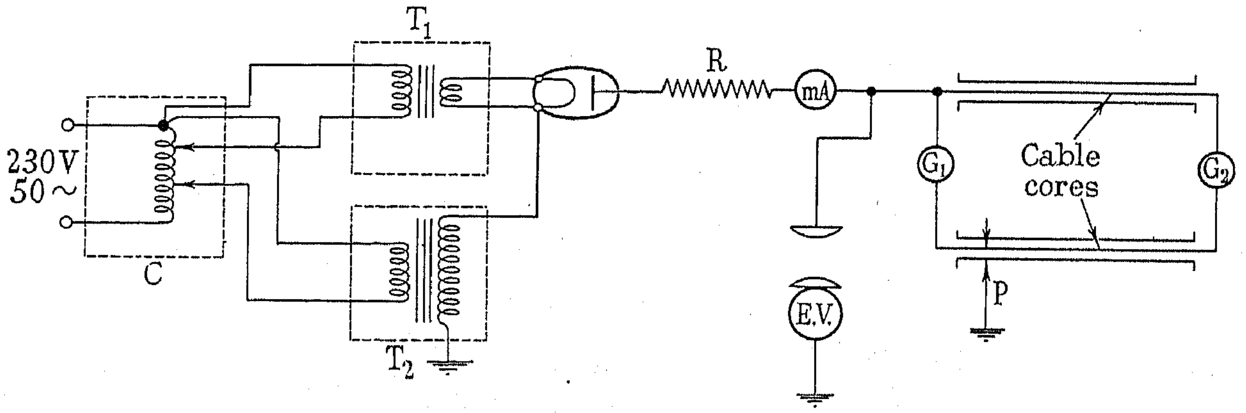

Fig. 3

C = control unit.
T₁ = filament transformer.
T₂ = high-tension transformer.
R = 2-megohm resistance.
mA = milliammeter.
E.V. = electrostatic voltmeter.
G₁, G₂ = ballistic galvanometers.
P = fault.

(a) Test Set

The high-voltage set is of the type in general use for making tests on cables after installation, and may incorporate either a valve or metal rectifier. The former is more generally used at present, and a set using valve rectification is therefore described in this paper. Fig. 3 shows the circuit of the apparatus arranged for a flashover location. The control unit is supplied with alternating current from a 230-volt source and is connected to a high-voltage transformer and to a step-down transformer which supplies the valve filament. The secondary of the step-down transformer is insulated to withstand the full testing voltage to earth.

One end of the secondary winding of the high-tension transformer is earthed, and the live end is connected through the half-wave valve rectifier, limiting resistance, and moving-coil milliammeter, to the cable on test. A high-tension electrostatic voltmeter is connected between the cable cores and earth, and the two cores on test are joined through the low-impedance ballistic meter. The cores at the far end of the cable are either short-circuited or connected by a similar meter.

(b) Ballistic Meter

The essential components of this instrument, which is shown in Fig. 4, consist of an insulated flat spiral of copper strip, against the face of which rests a light movable ring of aluminium. This ring is pivoted eccentrically and is thus free to move away from the fixed coil, which carries the discharge current from the cable cores. Each time a flashover occurs, the ring is repelled and moves a pointer over a scale of 100 equal divisions. A control spring returns the ring to the face of the coil at the end of the discharge, and a zero adjuster is provided in order that any slight movement from the zero position may be corrected.

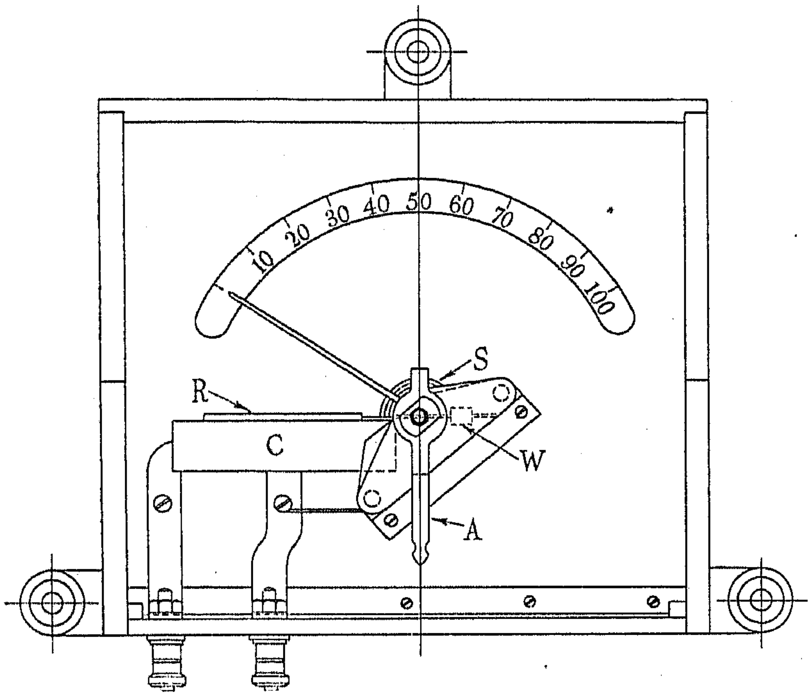

Fig. 4

R = aluminium ring.
C = coil.
S = control spring.
A = zero adjustment arm.
W = balance weight.

Since the instrument operates at a high voltage, insulating legs are fitted to the case, the interior of which is coated with aquadag to reduce electrostatic deflections.

The results given in this paper were obtained with an instrument of the type shown, but experiments have also been made with a meter in which a centrally pivoted ring is placed in a helical coil, the angle between the axis of the helix and the plane of the ring being 45°. The sensitivity of this instrument was, however, found to be poor.

(c) Operation

The set having been connected as shown, the filament transformer switch on the control unit is closed and the filament voltage adjusted to a value near its maximum.

The high-tension transformer switch is then closed and the voltage gradually raised until a flashover occurs, when the readings of the ballistic meter and the high-tension voltmeter are recorded.

(5) THEORY OF THE PHENOMENON

(a) The Discharge Current

At the instant before the flash occurs the cables are at potential V, say, and there is no current in them. The occurrence of the flash causes P to fall to zero potential, and the effect is to produce travelling waves which travel from P towards C and D. Let us call these waves W_1 and W_2 respectively. They are clearly equal, and have a voltage $-V$ and an associated current of magnitude V/Z, where $Z = \sqrt{(L/C)}$, is the surge impedance of the cable and is about 40Ω for power cables. The directions of current and wave propagation and the sign of the voltage are given by the formulae:—

$$I = E/Z \text{ for travel to the right}$$

and

$$I = -E/Z \text{ for travel to the left}$$

where E is the voltage of a wave and I its current in the right-hand direction. Since in our case $E = -V$, we have

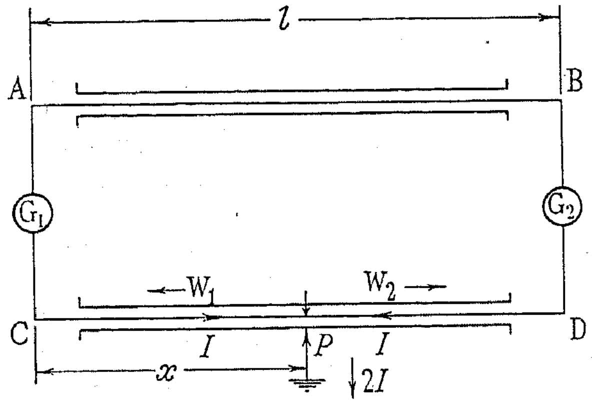

Fig. 5

$$I_1 = -(-V)/Z = \quad V/Z = I, \text{ say}$$

and

$$I_2 = \quad (-V)/Z = -V/Z = -I$$

The waves and their currents are shown in Fig. 5. Until W_1 or W_2 reaches a point in the loop the voltage is V and the current zero, but when one of the waves passes a point a current I flows and the voltage drops to zero. The current in G_1 is zero until W_1 reaches the left end of the loop at time x/v, where v is the velocity of the wave, and then jumps quickly to the value I. This current persists until the wave W_2 reaches G_1 by the path PDBAC at time $(2l - x)/v$, and is then neutralized by the current of wave W_2. The waves W_1 and W_2 traverse the loop in opposite directions and reach P at time $2l/v$, when there is again zero current in the loop and the potential is $V + (-V) + (-V) = -V$, since each wave lays down a voltage $-V$. The flash then reverses, and in the absence of dissipation the vacillating discharge would persist indefinitely and the currents at G_1 and G_2 would be those shown in Fig. 6. The effect of dissipation is difficult to determine with exactness, but reasonable accuracy may be obtained for fairly small dissipation in the following way. We can assume that the pulses of current die away in geometric ratio, the constant of diminution being

$$k = e^{-\frac{\alpha 2l}{v}}$$

where α is a decrement factor.

It can be seen that such an assumption is true provided k is not greatly different from unity, for the total discharge from P to earth is then

$$\frac{2l}{v}(2I - k2I + k^2 2I - k^3 2I \dots)$$

$$= \frac{2l}{v}\,\frac{2I}{1+k} \simeq \frac{2l}{v}I = \frac{2l}{v} \times \frac{V}{Z}$$

$$= \frac{2l}{\sqrt{\left(\frac{1}{LC}\right)}}\,\frac{V}{\sqrt{\left(\frac{L}{C}\right)}} = 2lCV$$

which is the initial charge on the conductors of the loop. In some tests it was found that k was about 0·8, and then an error of about 10 % is obtained for the total discharge; the error lies in the simplified assumptions for the voltage and current at any point of the loop. Thus it is not true to assume that each pulse has a constant magnitude for its duration, or that a voltage of exactly $-V$ is established at the end of the first cycle, and, moreover, we have ignored the resistance from P to earth, in which there is a dissipation of energy and across which there is a varying voltage-drop which must modify the voltage of the waves W_1 and W_2 and the succeeding waves.

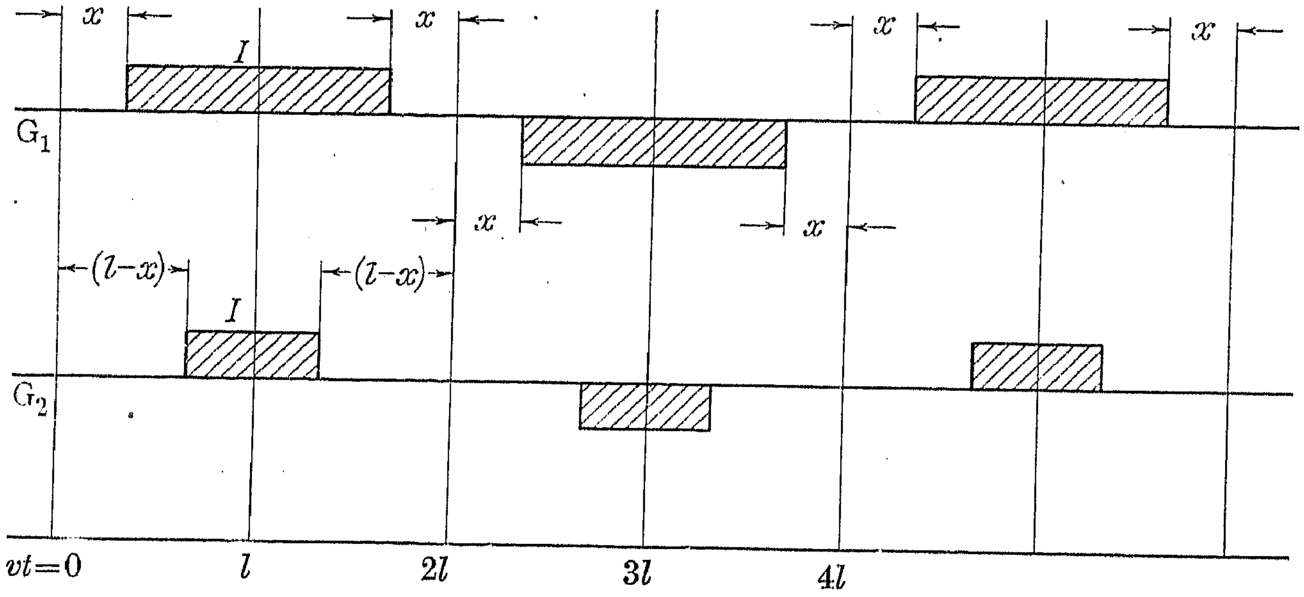

Fig. 6

The simplified picture, given above, will be used to explain the action of the ballistic meter, and then the effects of attenuation and distortion will be considered.

(b) The Deflection of the Ballistic Meter

In the earliest test made, a ballistic galvanometer of ordinary construction, plus a shunt, was used. This instrument proved unsatisfactory and succeeding instruments are of the repulsion type, in which the main current passes through a stationary thick copper coil or spiral and induces a current in an aluminium ring which can move away or rotate. One type of such an instrument is described in Section 4(*b*).

Let the primary winding carry a current i, the resistance and inductance of the aluminium ring be R_0 and L_0 respectively, and the mutual inductance be M. The current in the ring is i_0, where

$$R_0 i_0 + L_0\frac{di_0}{dt} = M\frac{di}{dt} \quad . \quad . \quad . \quad . \quad (4)$$

Let us assume for simplicity, and as a first approximation, that the current I consists of square pulses of the form shown in Fig. 6 and that the decay of the current in the ring is negligible for the short times of the pulses. It is then easy to show that i_0 must consist of square pulses of the same duration and pause. For let a pulse of the current i occur at $t = 0$, the value rising from zero to I; integrating equation (4) between $t = -\epsilon$ and $t = +\epsilon$, where ϵ is very small, we get

$$\int_{-\epsilon}^{\epsilon} R_0 i_0 dt + \int_{-\epsilon}^{\epsilon} L_0\frac{di_0}{dt}dt = \int_{-\epsilon}^{\epsilon} M\frac{di}{dt}dt$$

It is clear that i_0 must be always finite (in the present case it can never exceed its final value I_0), so that the first integral cannot exceed $2\epsilon R_0 I_0$ and is vanishingly small with ϵ; we can therefore neglect the first term. We have left

$$(L_0 i_0)^{+\epsilon}_{-\epsilon} = (Mi)^{+\epsilon}_{-\epsilon}$$

which gives $L_0 I_0 = MI$

or $I_0 = \frac{M}{L_0}I$ . . . . (5)

$$\left.\begin{aligned} L_0 I_0 &= MI \\ I_0 &= \frac{M}{L_0}I \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (5)$$

We consider first the case when I_0 does not decay appreciably during the time that i remains equal to I. Suppose now that at time T the current i falls from I to zero. We now integrate equation (4) from $T - \epsilon$ to $T + \epsilon$ and we get, as before,

$$(L_0 i_0)^{T+\epsilon}_{T-\epsilon} = (Mi)^{T+\epsilon}_{T-\epsilon}$$

We have $i_0 = I_0$ and $i = I$ at $T - \epsilon$

whilst $i = 0$ at $T + \epsilon$

The equation just written then gives

$$(L_0 I_0)_{T+\epsilon} - L_0 I_0 = 0 - MI$$

so that with the help of equation (5) we get

$$(i_0)_{T+\epsilon} = 0$$

In the simplified case it seems, therefore, that the current in the ring is (M/L_0) times the line current, and consists of similar square pulses.

It is expected, and oscillographic tests confirm this, that the total discharge is over within a millisecond, during which time the moving coil has not moved appreciably. The action is therefore truly ballistic, and as there is no permanent magnetic field there is negligible damping. The torque blow on the moving ring is

$$\mathbf{T} = K\int i i_0 dt$$

where K is a geometrical constant of the instrument. K is great when the ring is very near the copper spiral and decreases rapidly as the ring moves away from the spiral. Substituting for i_0 in terms of i we get

$$\mathbf{T} = \left(\frac{KM}{L_0}\right)\int i^2 dt$$

Let us find the torque blow for the upper pulse of Fig. 6, in which

$$i = 0 \quad \text{for} \quad 0 \leqslant t \leqslant \frac{x}{v}$$

$$i = I \quad \text{for} \quad \frac{x}{v} \leqslant t \leqslant \frac{2l - x}{v}$$

$$i = 0 \quad \text{for} \quad \frac{2l - x}{v} \leqslant t \leqslant \frac{2l + x}{v}$$

$$i = -kI \quad \text{for} \quad \frac{2l + x}{v} \leqslant t \leqslant \frac{4l - x}{v}, \text{ etc.}$$

The torque blow is then

$$\frac{KM}{L_0}I^2\left(\frac{2l - 2x}{v} + k^2\frac{2l - 2x}{v} + k^4\frac{2l - 2x}{v} + \cdots\right)$$

$$= \frac{KM}{L_0}I^2\left(\frac{2l - 2x}{v}\right)\frac{1}{1 - k^2}$$

For the lower pulse the torque blow is

$$\frac{KM}{L_0}I^2\left(\frac{2x}{v}\right)\frac{1}{1 - k^2}$$

The torque blow produces an angular velocity $\omega = \mathbf{T}/\mathbf{I}$, where $\mathbf{I}$ is the moment of inertia of the moving system. The kinetic energy produced by the blow is $\frac{1}{2}\mathbf{I}\omega^2$ and winds up the control spring to a maximum deflection d, at which position the whole of the kinetic energy has been converted into potential energy of the spring of amount $\frac{1}{2}sd^2$, where s is the stiffness of the spring. Equating we get

$$\tfrac{1}{2}\mathbf{I}\omega^2 = \tfrac{1}{2}sd^2$$

or

$$d = \omega\sqrt{\frac{\mathbf{I}}{s}} = \mathbf{T}\sqrt{\frac{1}{\mathbf{I}s}}$$

We have therefore

$$d_1 = \frac{KM}{(1 - k^2)L_0\sqrt{\mathbf{I}s}}I^2\frac{2l - 2x}{v}$$

$$= \frac{KM}{(1 - k^2)L_0\sqrt{\mathbf{I}s}}\frac{1}{Z^2}V^2\frac{2l - 2x}{v}$$

and

$$d_2 = \frac{KM}{(1 - k^2)L_0\sqrt{\mathbf{I}s}}\frac{1}{Z^2}V^2\frac{2x}{v}$$

It is seen that the deflection is proportional to the distance of the fault from the opposite end and to the square of the voltage. The meter measures, in fact, $V^2 l$, not (charge)^2, which is $V^2 l^2$. Dividing d_1 by d_2 we find

$$\frac{d_1}{d_2} = \frac{l - x}{x} \quad \ldots\ldots \quad (6)$$

giving

$$x = \frac{d_2}{d_1 + d_2}l$$

which is the first and simplest equation.

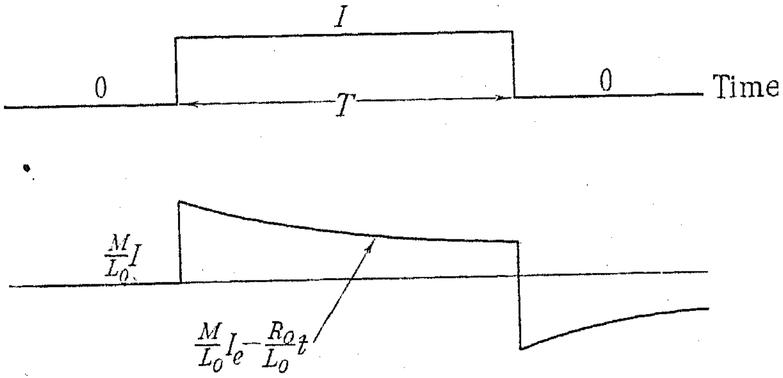

Fig. 7

If the first test is made at voltage V_1 and the second at voltage V_2, we find that

$$\frac{d_1}{d_2} = \frac{V_1^2}{V_2^2}\frac{l - x}{x}$$

or

$$\frac{d_1}{d_2'} = \frac{l - x}{x}$$

where

$$d_2' = d_2\left(\frac{V_1}{V_2}\right)^2$$

so that

$$x = \frac{d_2'}{d_1 + d_2'}l$$

This proves equation (3).

Let us now consider the decay of current in the ring due to its resistance R_0. The current jumps up to MI/L_0 at the beginning of the pulse of line current, decays according to the exponential law

$$\frac{M}{L_0}Ie^{-\frac{R_0}{L_0}t}$$

during the pulse, decreases by MI/L_0 at the end of the pulse of line current to a value

$$-\frac{M}{L_0}I(1 - e^{-\frac{R_0}{L_0}T})$$

and then decays to zero thereafter until the next pulse arrives. The form of the current is shown in Fig. 7.

The torque blow for a pulse of line current is then:—

$$\mathbf{T} = K\frac{M}{L_0}I^2\int_0^T e^{-\frac{R_0}{L_0}t}dt$$

$$= K\frac{M}{R_0}I^2(1 - e^{-\frac{R_0}{L_0}T})$$

It follows, therefore, that for such a case

$$\frac{d_1}{d_2} = \frac{1 - e^{-\frac{R_0}{L_0}\left(\frac{2-2x}{v}\right)}}{1 - e^{-\frac{R_0}{L_0}\left(\frac{2x}{v}\right)}}$$

$$= \frac{e^{-\frac{R_0}{L_0}\left(l-\frac{2x}{v}\right)} \sinh \frac{R_0(l - x)}{L_0 v}}{\sinh \left(\frac{R_0 x}{L_0 v}\right)}$$

This reduces to equation (6) when R_0 is very small. If R_0 is not small enough to be neglected, the divergence of the ratio in equation (6) from that in equation (7) can be allowed for in the way shown in equation (1). In this method we put

$$m = \frac{d_1 + d_2}{d_2} \times \frac{x}{l}$$

$$= \frac{e^{-\frac{R_0}{L_0}\left(\frac{l-2x}{v}\right)} \sinh \frac{R_0(l - x)}{L_0 v} + \sinh \frac{R_0 x}{L_0 v}}{\sinh \frac{R_0 x}{L_0 v}} \times \frac{x}{l}$$

It is easy to see that m is always unity when the fault is near the middle of the length. When the fault is near the beginning of the cable, we have

$$m \simeq \frac{e^{-\frac{R_0 l}{L_0 v}} \sinh \frac{R_0 l}{L_0 v}}{\frac{R_0 l}{L_0 v}} \quad . \quad . \quad . \quad . \quad (7)$$

This value of m is always less than unity. In one instrument it was estimated that $R_0 \simeq 0 \cdot 0006\,\Omega$, $L_0 \simeq 4 \times 10^{-8}$ H. Considering a cable of dielectric constant 3·6, v is equal to 186 000 miles per second divided by $\sqrt{(3 \cdot 6)}$, i.e. 100 000 miles per second (approx.). Then

$$\frac{R_0 l}{L_0 v} \simeq 0 \cdot 15 l$$

where l is in miles. For a route length of 1 mile m is 0·865, and for 3 miles m is 0·66. When the fault is about a quarter of the length from the beginning, then m is 0·94 for a mile length and 0·86 for a 3-mile length.

The effect of damping in the moving coil of the instrument is to decrease the larger deflection by a greater fraction than the smaller; this is because the larger deflection is due to a longer pulse of current, which suffers more decay because of its longer duration than the shorter pulse. It appears thus that m should be always less than unity if the damping in the instrument were the main cause. Field measurements show that m is invariably greater than unity, and the reason for this is given in the next Section.

(c) Correction Factor, *m*

It is necessary to look for the main cause of the factor m in the phenomenon of discharge, and here there are two possibilities. Firstly the amplitude, i.e. the crest value, of the wave diminishes with time and distance of travel; secondly the head and tail become flattened. The resistance of P to earth will cause a considerable drop in the crest.

Let us consider first the diminution of crest value, and suppose that the wave diminishes exponentially as it travels. Then at any point of the line the current is of the form $i = Ie^{-\alpha t}$, as shown in Fig. 8. Let us also ignore the damping in the instrument, so that the equation for i_0 is

$$L_0\frac{di_0}{dt} = M\frac{di'}{dt}$$

giving $i_0 = (M/L_0)i$, the constant of integration being zero. The torque blow is

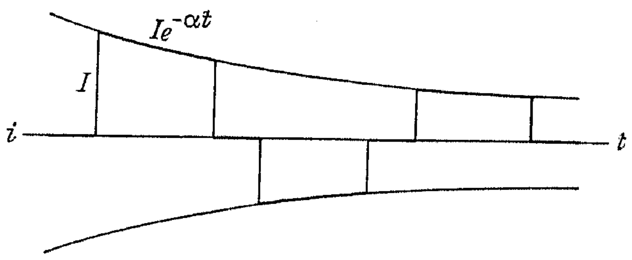

Fig. 8

$$\frac{KM}{L_0}\int_0^T I^2 e^{-2\alpha t}dt$$

$$= \frac{KM}{L_0}\frac{I^2}{2\alpha}(1 - e^{-2\alpha T})$$

Let the wave start with amplitude I_0. By the time it reaches G, viz. at $t = x/v$, its amplitude is

$$I_1 = I_0 e^{-\frac{\alpha x}{v}}$$

The duration at this point is, by Fig. 6, $(2l - 2x)/v$, so that

$$d_1 \propto I_0^2 e^{-\frac{2\alpha x}{v}}\left[1 - e^{-\frac{2\alpha(2l - 2x)}{v}}\right]$$

Similarly $$d_2 \propto I_0^2 e^{-\frac{2\alpha(l-x)}{v}}\left[1 - e^{-\frac{2\alpha 2x}{v}}\right]$$

so that $$\frac{d_1}{d_2} = \frac{e^{-\frac{2\alpha x}{v}}\left[1 - e^{-\frac{2\alpha(2l-2x)}{v}}\right]}{e^{-\frac{2\alpha(l-x)}{v}}\left[1 - e^{-\frac{2\alpha 2x}{v}}\right]}$$

$$= \frac{e^{\frac{2\alpha(l-x)}{v}} - e^{-\frac{2\alpha(l-x)}{v}}}{e^{\frac{2\alpha x}{v}} - e^{-\frac{2\alpha x}{v}}}$$

$$= \frac{\sinh \frac{2\alpha(l - x)}{v}}{\sinh \frac{2\alpha x}{v}}$$

Then
$$m = \frac{d_1 + d_2}{d_2} \cdot \frac{x}{l}$$
$$= \frac{\sinh \dfrac{2\alpha(l - x)}{v} + \sinh \dfrac{2\alpha x}{v}}{\sinh \dfrac{2\alpha x}{v}} \cdot \frac{x}{l}$$
$$= \frac{\sinh \dfrac{\alpha l}{v} \cosh \dfrac{\alpha(l - 2x)}{v}}{\sinh \dfrac{2\alpha x}{v}} \cdot \frac{2x}{l} \quad . \quad . \quad . \quad (8)$$

For a given route length l, m is a maximum when x is zero and has then the value
$$\frac{\sinh \dfrac{2\alpha l}{v}}{\dfrac{2\alpha l}{v}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8a)$$

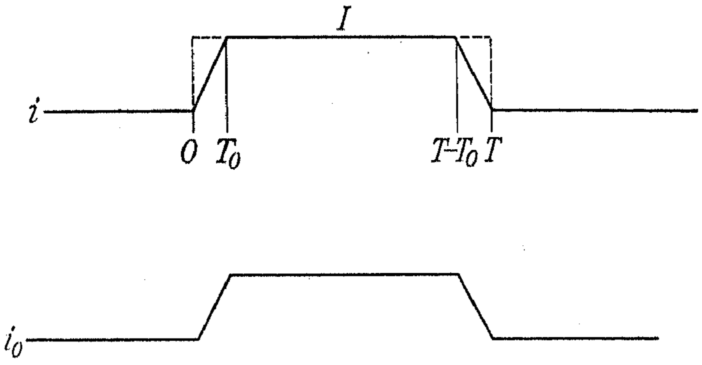

Fig. 9

In an oscillographic test it was found that a wave travelling round a loop of 2 × 400 yards suffered a diminution of about $0\cdot 6$, so that
$$l^{-\alpha\frac{2 \times 400}{1\,760v}} = 0\cdot 6$$
giving
$$\frac{\alpha}{v} = 1\cdot 0$$

Then the maximum m for a route length of l miles is $\sinh 2l/2l$; thus for a route length of 1 mile the maximum value of m is about $3\cdot 6$. It is clear that this source of error is very important and must be allowed for. Comparing equations (7) and (8a), we see that the effect of the instrument damping is to decrease the effect of the line damping by a small amount, which is quite masked because of the following.

We have further to consider the effect of the flattening of the head and tail of the waves. Let us consider an ideal case, shown in Fig. 9, in which the line current increases from zero to I in time T_0, remains I from T_0 to $T - T_0$, and decreases from I to zero from $T - T_0$ to T. If we ignore the resistance of the meter ring, we find again that the current in the ring is (M/L_0) times the line current. The torque blow is then
$$K\frac{M}{L_0}\int_0^T i^2 dt$$
$$= K\frac{M}{L_0}\left[\int_0^{T_0}\left(\frac{I}{T_0}t\right)^2 dt + \int_{T_0}^{T-T_0} I^2 dt + \int_{T-T_0}^{T}\left(\frac{I}{T_0}T - t\right)^2 dt\right]$$
$$= K\frac{M}{L_0}I^2\left(T - \frac{4}{3}T_0\right)$$
instead of $K\dfrac{M}{L_0}I^2T$.

If $T_0 = \frac{1}{2}T$, the torque blow is reduced to one-third of its value. There may even be a worse case, viz. when the pulse does not reach its full value I, as indicated in Fig. 10.

It would be very difficult to obtain a formula to allow for the distortion of the head and tail of the pulses, and no attempt has been made to do so. Instead the value of α has been increased by a certain amount to allow for it. The extra allowance is guided by the results of localizations made in the field, and it is very gratifying that the form of m found above seems an accurate way of allowing for the distortions. We take $\alpha/v = 1\cdot 8$, instead of $1\cdot 0$, and we then get
$$m = \frac{\sinh 1\cdot 8l \cosh 1\cdot 8(-2x)}{\sinh 3\cdot 6x} \cdot \frac{2x}{l}$$

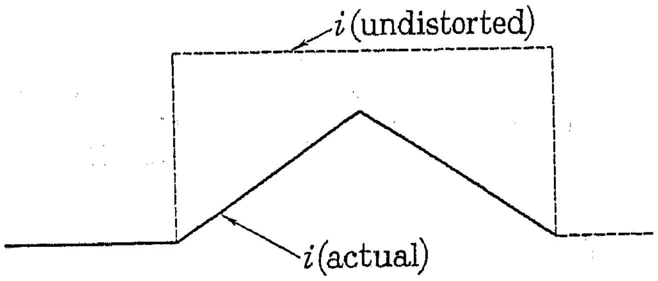

Fig. 10

This form is not suitable for use, as we do not know x, and a transformation is necessary. Expanding $\cosh 1\cdot 8(l - 2x)$ and dividing by $\sinh 3\cdot 6x$ we get
$$m = \frac{2x}{l}\sinh 1\cdot 8l(\cosh 1\cdot 8l \coth 3\cdot 6x - \sinh 1\cdot 8l)$$
giving
$$\coth 3\cdot 6x = \frac{ml}{x \sinh 3\cdot 6l} + \tanh 1\cdot 8l$$

But by equation (1), which defines m,
$$x = m\frac{d_2}{d_1 + d_2}l, \text{ or } \frac{ml}{x} = \frac{d_1 + d_2}{d_2}$$
so that
$$\coth 3\cdot 6x = \frac{d_1 + d_2}{d_2 \sinh 3\cdot 6l} + \tanh 1\cdot 8l$$

Given l, d_1, and d_2, we can find x from this equation, and thus m. Fig. 2 gives the value of m in terms of l and $d_2/(d_1 + d_2)$. The procedure is thus to calculate $d_2/(d_1 + d_2)$ from the observed values of d_1 and d_2, look up the value of m from Fig. 2, and the distance of the fault is calculated by the formula
$$x = m\frac{d_2}{d_1 + d_2}l$$

(6) OSCILLOGRAPHIC TESTS

It was considered desirable to obtain some visual record of the discharge phenomena, and at the same time to verify the equations

$$\mathrm{CP} = \frac{d_2}{d_1 + d_2} \times \mathrm{CD}$$

and $$d_2' = d_2\left(\frac{V_1}{V_2}\right)^2$$

under controlled conditions, i.e. to verify that the meter reads V^2l under the conditions of discharge. There was also at first some doubt as to whether the discharge was vacillating or unidirectional, and it was felt that an oscillographic test would best decide the matter.

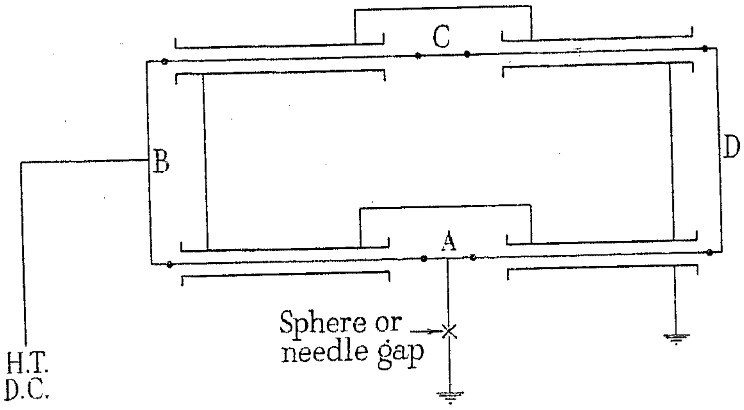

Fig. 11

A test loop was made by 4 drum lengths of 0·25-sq. in. 66-kV single-core cable, each length being 199 yards. The sheaths were bonded and earthed, and the conductors formed the loop. The arrangement is shown in Fig. 11. A sphere or needle gap at A formed the flashing fault.

(a) Verification of the V^2l Law

The meter was placed at A, B, and C, and the readings for various voltages of flashover were the following. A sphere gap was used in this case.

Voltage	Deflection	$\left(\frac{40}{V}\right)^2 \times$ Deflection
Meter at A		
23 kV	5·0	15·1
30 kV	8·5	15·1
40 kV	15·0	15·0
Meter at B		
18 kV	1·5	7·4
25 kV	2·5	6·4
30 kV	4·5	8·0
40 kV	8·0	8·0
Meter at C		
No deflection		

It is seen that the V^2 law is well satisfied at A and reasonably well at B. The deviations in the latter case may be due to the fact that the readings were small and that accuracy is not possible within a quarter of a division.

The average reading at A, reduced to 40 kV flashover, is 15·1 and at B it is 7·5, so that the l law is satisfied. Thus in combination the V^2l law is seen to hold.

(b) Form of the Discharge Current

Fig. 12 shows one of several arrangements used for obtaining the current curve of the discharge. A concentric resistance of 1·2 Ω was placed in the loop, and the voltage-drop across it due to the discharge current was fed via two capacitances of 0·00035 μF to the delay cable. The delay cable had an impedance of 60 Ω but was incorrectly terminated by a resistance of 50 000 Ω, for if it had been correctly terminated there would have been an insufficient voltage on the oscillograph plates. The rather small capacitances of 0·00035 μF were provided by pieces of cable, and were used to prevent the d.c. voltage from reaching the delay cable and oscillograph plates. Under these circumstances drastic reflections occur, but the form of the discharge current can nevertheless be seen quite clearly in Fig. 13 (see Plate 1, facing page 708). Ignoring the initial reflections, which die down after three pulses, we see that there are periods of small current followed by the main discharge pulses. The time sweep is 114 microseconds.

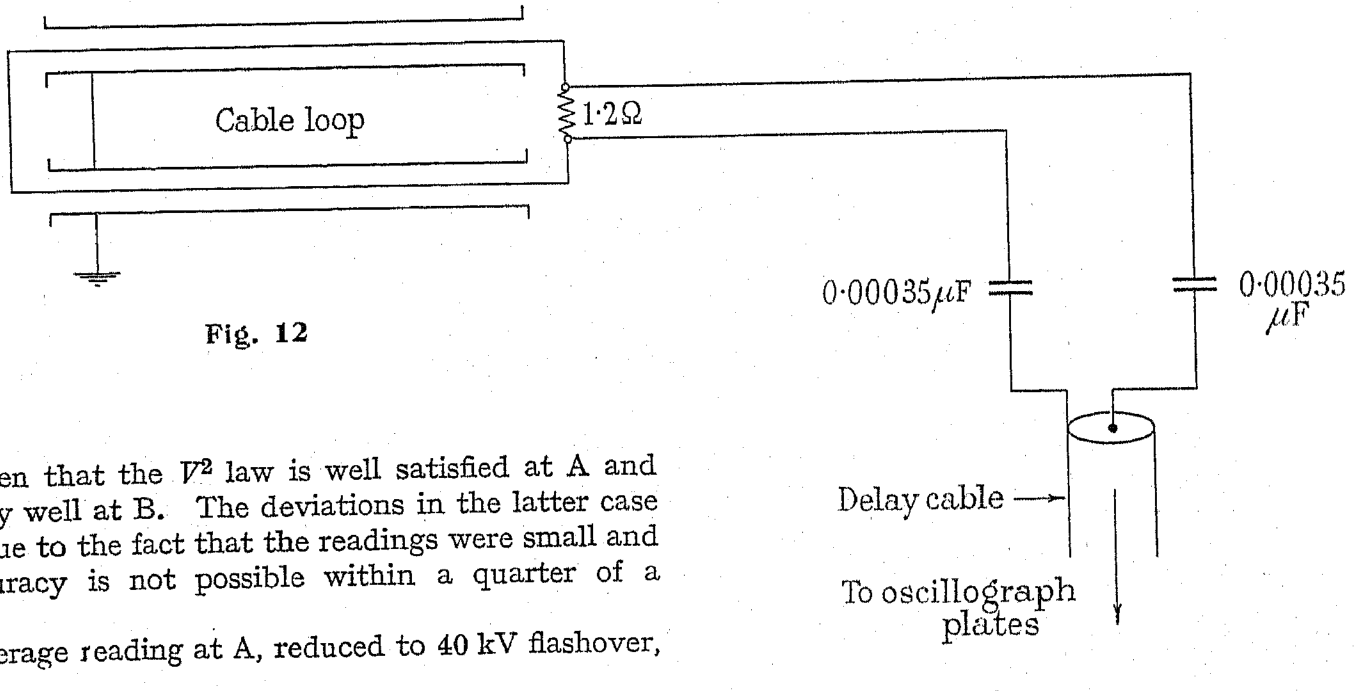

Fig. 12

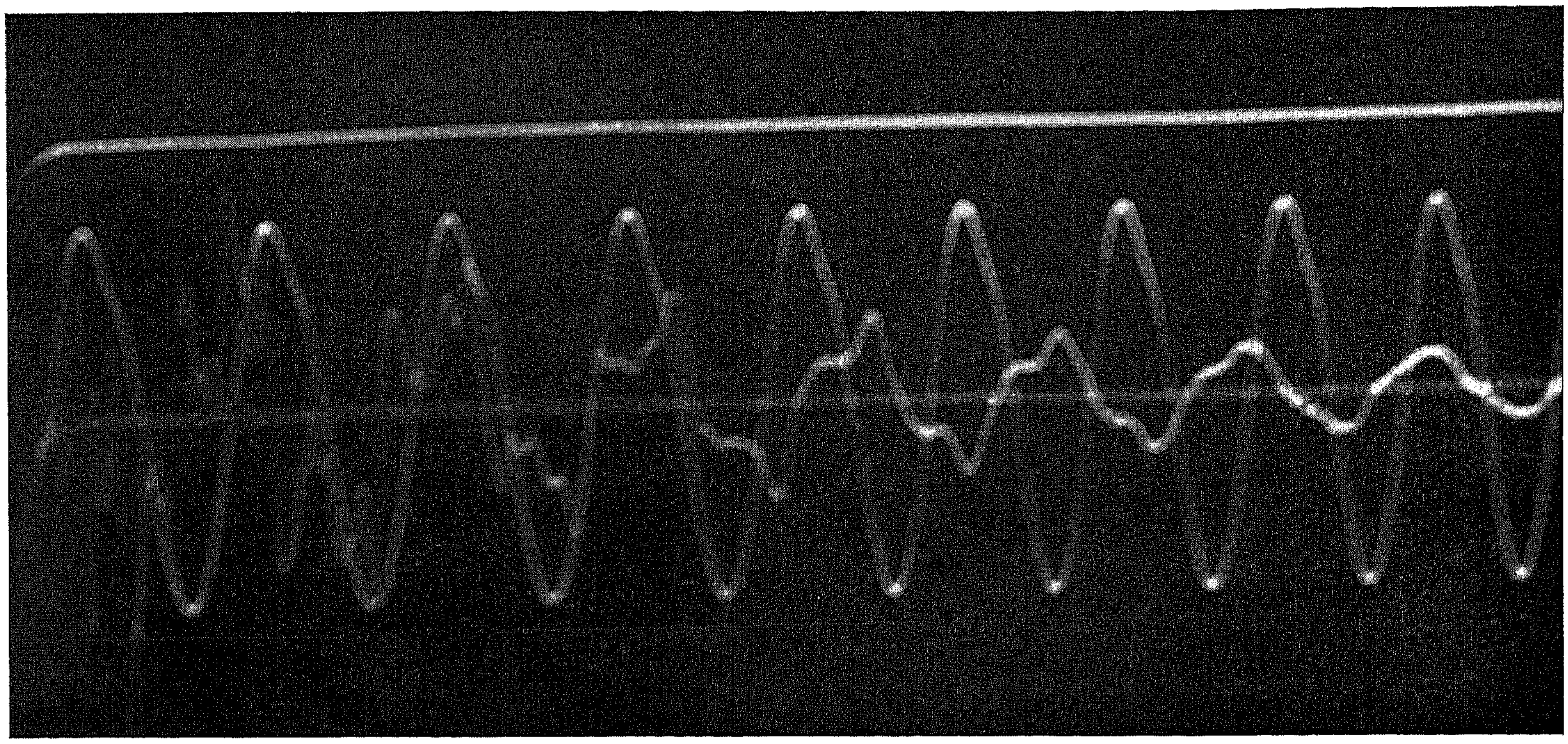

Fig. 13

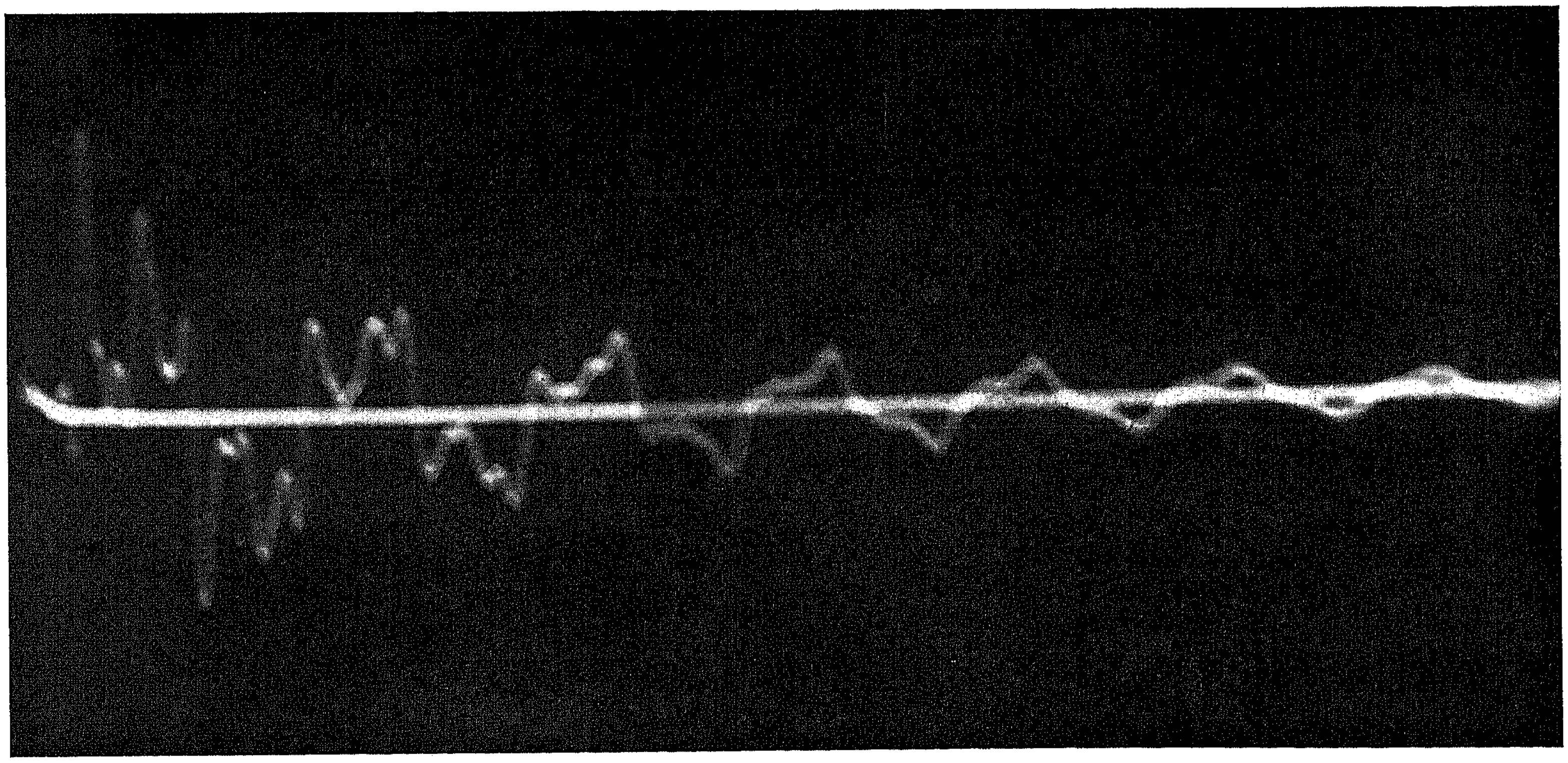

Fig. 14

Plate 2

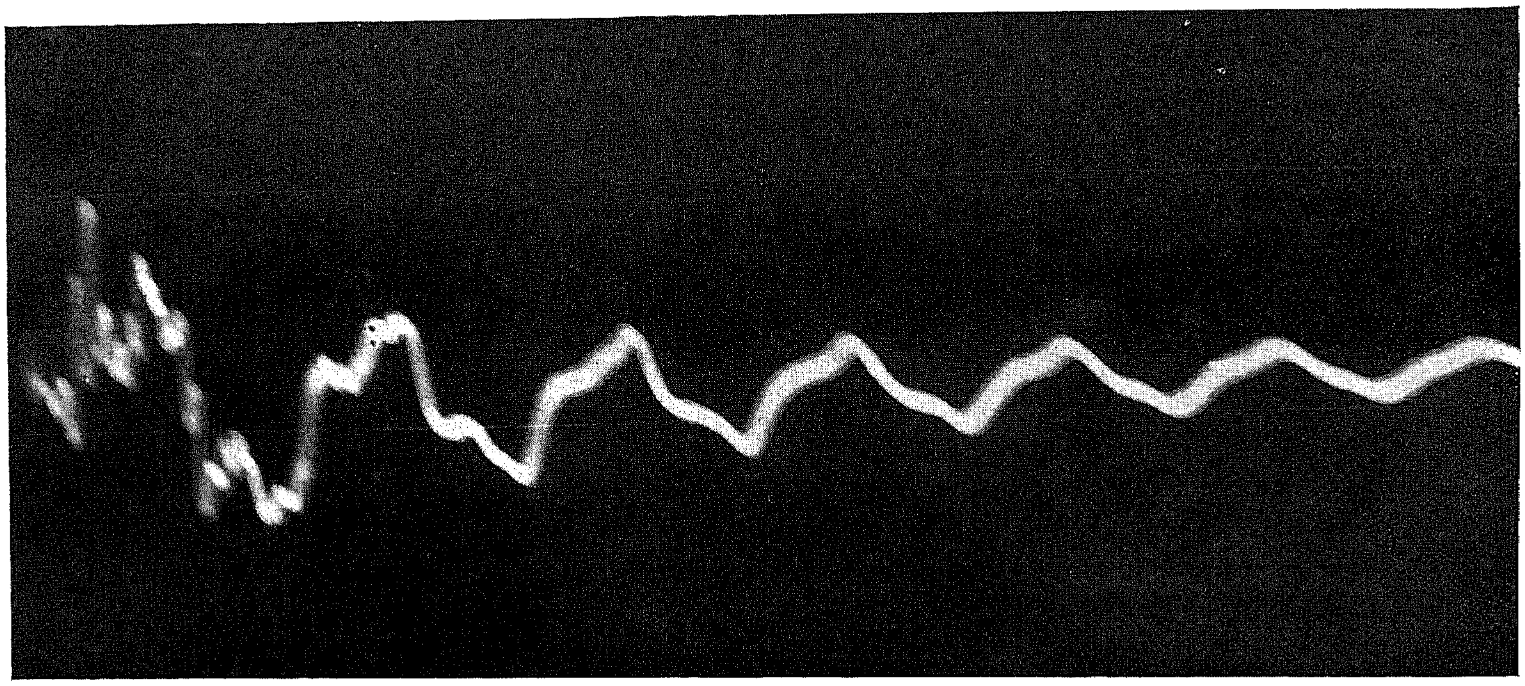

Fig. 15

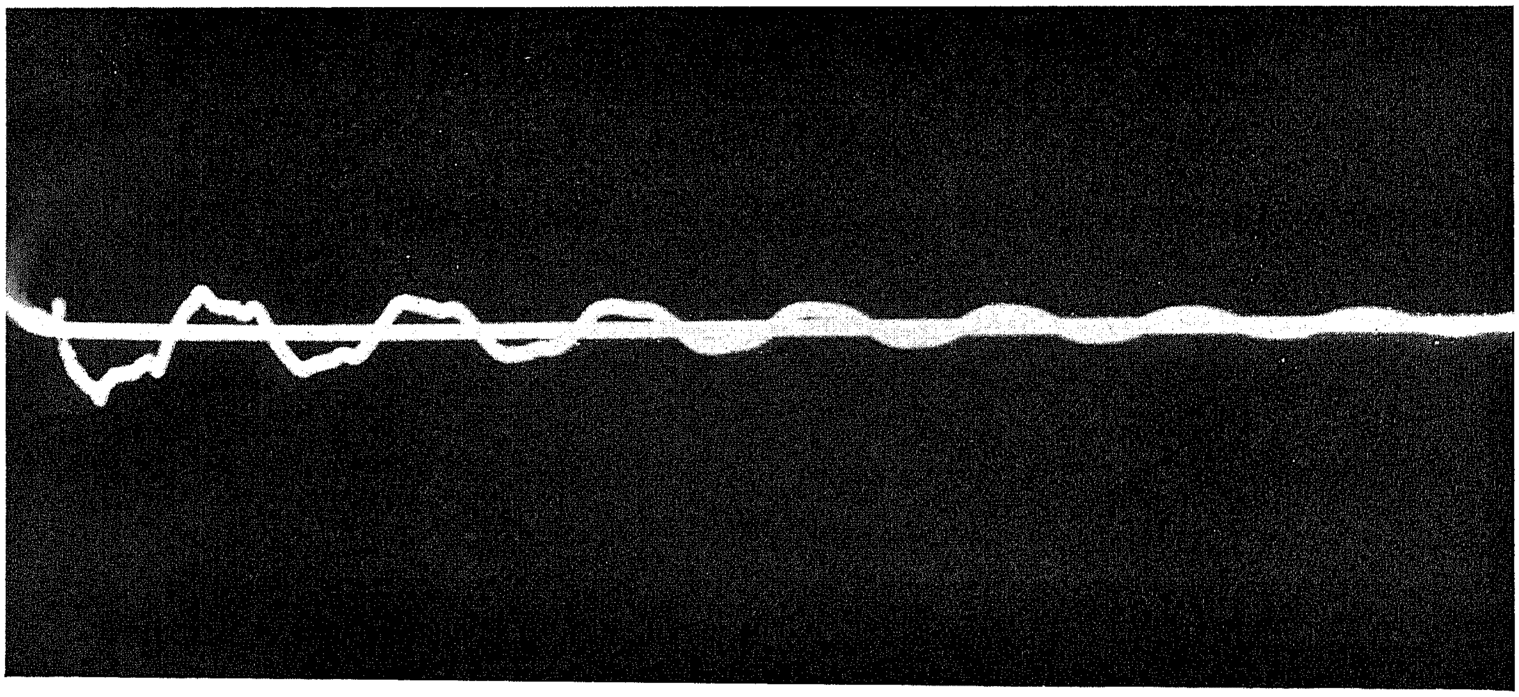

Fig. 16

Fig. 14 (Plate 1) shows the discharge current measured by the arrangement of Fig. 12 with the following modifications. The voltage-drop was taken off $1\cdot 93\,\Omega$ of a $3\cdot 3\,\Omega$ concentric resistance, and $0\cdot 005\,\mu$F was put across the input side of the delay cable. The initial reflections are not much reduced, but during the quiescent periods the current does fall to zero. Fig. 15 (Plate 2) shows the current for the case when $0\cdot 02\,\mu$F was put across the input of the delay cable, other circuit details being the same as for Fig. 14. In this case the initial reflections have been almost completely suppressed, but at the cost of rounding the main discharge wave. From Fig. 14 we find that $e^{-\alpha l/v}$ is $0\cdot 6$ for a length of 800 yards.

Attempts were made to avoid using the isolating condensers by replacing them by a transformer. Reflections were eliminated, but leakage inductance destroyed the clear character of the discharge; the resulting oscillograph is shown in Fig. 16 (Plate 2).

ACKNOWLEDGMENTS

The authors are indebted to Messrs. Callender's Cable and Construction Company, Ltd., for permission to publish this paper.

DISCUSSION ON "NON-DESTRUCTIVE TESTING"*

FURTHER REPLY

Messrs. H. H. Lester, R. L. Sanford, and N. L. Mochel (*in reply*):

Radiographic Methods.†

Dr. Lester, who was chiefly responsible for the radiographic section of the paper, desires to call attention to the fact that this section of the paper was intended to give a picture of radiography from the point of view of the industrial user of the method rather than from that of the research laboratory. It is considered interesting and valuable to know to what extent the method has been adopted by industry and to what extent it has been found reliable in improving service performance of castings and weldments.

Mr. Stephens remarks that the radiographic method is used more extensively in Germany and England than it is in the United States, as judged by the number of radiographic installations. However, our paper indicated 88 instead of 57–60 X-ray plants and, in addition, an extensive use of radium. It is hoped that the wide European use of the method by industry will be reflected in papers written from the point of view of production.

One shop problem that Mr. Stephens calls attention to is that of radiographing drums from the inside. This problem has been encountered in America. If it could be done, it would provide an excellent method for examining field welds in welded pipe. Simple geometric considerations show that there must be proper relationships between the distance from film to flaw, the distance from flaw to source of radiation, and the dimensions of the source, in order to produce a sharp image of the flaw. These considerations prevent this use of the method in most cases.

We agree with Mr. Wiltshire that X-ray tubes of higher than 300 kV are necessary in industry. Welds in metal sections of 4 in., and even 5 in., are encountered through which radiographs are desired. Present data indicate the superiority of pictures made with 400 kV over those made with 200 kV through metal above 2 in. in thickness. The question involved in higher X-ray voltages is tied up with secondary radiation. If superior values of the ratio of primary to secondary radiation can be obtained at higher voltages, then the higher-voltage tubes are justified. Dr. Pullin reports results on this problem in his paper, but his voltage range is too narrow. Work now in progress in America considers a much wider survey. Results, when available, will be presented through Committee E–7 of the American Society for Testing Materials.

Mr. Wiltshire mentions the penetrameter problem. The importance of this to industry is not fully realized. With present commercial equipment, a crack system $\frac{1}{8}$ in. in thickness is not detectable in practical testing in a metal section 2 in. in thickness, yet such a defect might be very injurious. The wire type of penetrameter of Mr. de Graaf is of very little assistance in determining the crack sensitivity of radiographs. Neither is the stepped penetrameter of Mr. Wiltshire. The use of actual crack systems in penetrameters is a development since the American contribution was written. These appear to be much superior to others that have been used in giving dependable information as to the ability of radiographic negatives to show fine cracks.

The remark of Dr. Betteridge with regard to segregations in stainless steels is endorsed. It has been found that in cast stainless steels of sections up to 3 in. in thickness, radiographic negatives have shown interdendritic segregation. The question of stress distribution brought up in the question that Mr. Desch addresses to Mr. de Graaf may be answered, so far as American practice is concerned, in the affirmative. That is, stress distribution may be determined by X-ray diffraction methods employing the method of Glöcker. However, this method is too difficult of application to be a practical shop method.

Mr. Bailey remarks that there is no reliable method for determining fissures of the order of $0\cdot 0001$ in. or $0\cdot 001$ in. in thickness. It is pointed out that he has omitted an important dimension, that is, he has not indicated the depth of the defect. Defects of the thickness he has indicated could be detected through $\frac{1}{8}$ in. of metal, provided the depth of the defect was $\frac{1}{8}$ in., but would be lost in metal $1\frac{1}{2}$ in. in thickness if the depth were no more than $\frac{1}{8}$ in. An artificial "crack," whose thickness is 0·0006 in. and whose depth varies from $\frac{1}{32}$ in. to $\frac{1}{4}$ in., is used regularly in testing with the test block described in the American paper.

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* See pages 517–595.

† Released for publication by the Chief of Ordnance of the U.S. Army. Statements and opinions are to be understood as individual expressions of their authors, and not those of the Ordnance Department.

Dr. Shearer remarks that a considerable amount of work remains to be done with a view to determining how important are defects revealed in radiographic negatives with regard to service performance. Data are accumulating slowly that will show such correlations. For weldments, it is hardly necessary to demonstrate the undesirability of fine cracks and other stress raisers. The presence of slag inclusions and cavities is evidence of improper welding practice. The radiographic evidence is used in such cases more to control the welding practice than to condemn the weld. In the case of castings, the seriousness of a flaw depends on various factors, so that a defect that is important in one case is not important in another. We sympathize with Dr. Shearer's view, but are of the opinion that aside from the difficulty in obtaining authoritative information there would be difficulties in applying it because of the various special conditions that arise.

Magnetic and Electrical Methods.

In view of the limited space allotted to the paper on practice in the U.S.A. it was not feasible to cover in detail the numerous applications of magnetic and electrical methods in present use. For this reason little consideration was given to methods employed solely for the purpose of determining magnetic or electrical properties of materials. As Prof. Wales indicates, many such methods are in use and more are in process of development.

For the same reason, no attempt was made to discuss in detail the technique of magnetographic testing. The practical value of the method is clearly brought out by the discussion, which tends to emphasize two points, namely that the best technique to employ in a given instance depends upon the type of piece to be tested and that valid interpretation of the results can only be made in the light of experience. The difference of opinion regarding whether it is better to work on remanent flux or while the magnetizing current is on is a case in point. Under the proper conditions, each view is correct. Many factors are involved, such as the shape of the piece, the probable location of defects, and the magnetic characteristics of the material. It is not safe to rely upon a general rule with regard to this point. The same might be said with regard to other questions such as d.c. versus a.c. magnetization, wet versus dry application, proper degree of magnetization, and the like. The theoretical foundation of the method is relatively simple, but its application generally requires the use of considerable ingenuity for best results.

Mr. Hannah asks whether any mechanism has been developed for continuous handling of tests on steel strip. It is not clear whether he refers to tests of magnetic properties as such or to tests classed as magnetic analysis. Apparatus has been developed for testing single sheets for core loss but, so far as we are aware, no apparatus is available for handling strip steel. For magnetic analysis, however, it should be noted that the apparatus mentioned on page 572 is stated to be applicable to material such as "bars, tubes, sheets, and strips."

One other point might be mentioned. Mr. Hoare speaks of an electromagnetic method for testing the thickness of non-magnetic coatings on a magnetic base, now in process of development. It may be of interest to note that the electric thickness gauge mentioned on page 574 has been in successful commercial use for several years.

Regarding Dr. Bailey's reference to the use of the magnetic dust method in the United States, one of us has used it continuously as a laboratory method since 1919, and since 1925 it has been adopted as a routine matter on all drop-forged stainless-steel turbine blades. Much progress has been made in recent years in the development of better powders, quite fine and coloured to suit some conditions better.

With reference to Mr. Benson's Fig. H, showing fatigue cracks on the ends of all the teeth on a pinion, the "dry dust" Magnaflux method has often been applied in the United States to the pinions of large marine propulsion reduction-gears as a routine matter during overhaul periods.

Relative to Mr. Reed's question, and his reference to spurious indications on hardened and ground crankshafts, one of us has had similar experience in carburized 5 % nickel-steel wrist pins for Diesel engines. Gauging appeared to be the cause of the markings revealed by the magnetic test. The drawing of the grinding wheel back across the surface upon finish grinding, in order to clear the work, even though apparently it removed no metal, appeared also to be a reason.

General Methods.

We note Mr. Benson's remark that the procedure referred to by the American authors for testing turbine rotors by a combination of different testing methods was originated in England. The testing of rotor forgings was, as stated in the paper, mentioned merely as an example and no credit was claimed as to originality. We believe, however, that these methods were being developed in the United States over the same period as that during which they were being developed elsewhere; they have apparently been more widely adopted in the United States than in England. Undoubtedly, Dr. Bailey is the originator of the magnetic examination of the bore of such large forgings.

Mr. Shannon raises a question relative to overspeed testing of turbine units. The reference in the paper on page 577 had only to do with the testing of the rotor proper, not necessarily in the turbine casing, and running up to an agreed-upon overspeed for some definite time period and then back to normal speed.

The following corrigenda to the paper should be noted:—

Page 566, col. 2, line 12 from the bottom of the column: *For* "negative was" *read* "negatives were".

Page 569, col. 2, lines 8, 9, and 10: *Delete* all the words after the word "specimen" in line 8, and the whole of lines 9 and 10.

Page 570, col. 1, line 3 from the bottom of the column: *For* "0·66 in." *read* "0·06 in.".

Fig. 5 on Plate 13 facing page 572: *For* "Magnaflux Corporation" *read* "National Bureau of Standards".

Page 579, col. 1, line 4 from the bottom of the column: *For* "A. Breuner" *read* "A. Brenner".

Page 579, col. 2, line 1: *For* "A. Breuner" *read* "A. Brenner".

THE ATTENUATION AND DISTORTION OF TRAVELLING WAVES ON OVERHEAD POWER TRANSMISSION SYSTEMS AT VOLTAGES BELOW THE CORONA LIMIT*

By B. G. GATES, Ph.D., Associate Member.†

(*Paper first received* 17*th February, and in revised form* 6*th July,* 1938.)

SUMMARY

A solution due to Jacottet, of the problem of the distortion of a vertical-fronted voltage wave of infinite length as it travels along a simple line, is used as a basis for the development of formulae and curves for the attenuation and distortion of chopped waves, and of waves with vertical or finite fronts and exponential tails. These results are employed to show how to obtain limiting values for the original shape and amplitude, and distance travelled of a wave recorded at any point on a simple line, and also to calculate its behaviour at any other point.

Using Bekku's method of subdivision of waves, formulae and curves are developed to calculate the attenuation and distortion of waves on single- and three-phase power transmission systems for disturbances in any or all lines, and it is shown how phenomena observed in practice may be accounted for. The effect of earth wires is also considered.

The results obtained are compared with oscillograms of artificially produced surges in three-phase power transmission lines, and excellent agreement is obtained.

(1) INTRODUCTION

The study of the behaviour of travelling waves on overhead transmission systems at voltages below the corona limit is of considerable importance, particularly on the very large number of systems which operate at voltages up to about 11 kV. In such systems the corona voltage is usually many times the normal working voltage, so that the impulse flash-over voltage of the line insulators is of the same order as or less than the corona voltage, i.e. surges not causing insulator flash-over must have maximum values not appreciably exceeding the corona voltage, while those causing flash-over are "chopped" at a similar maximum value.

It thus appears necessary to consider two types of wave, viz. chopped waves and waves with tails dying away exponentially. It is also found necessary to distinguish between waves travelling on different numbers of conductors on single- and three-phase lines, but the problem is first considered from the standpoint of a simple line and it is then extended to include single- and three-phase power transmission lines, with and without earth wires.

It is easily shown that the solution of the well-known "telegraph" equation‡ is inadequate to account for the attenuation and distortion observed in travelling waves on overhead power transmission systems. At voltages below the corona limit, the only important sources of attenuation and distortion in overhead lines, other than those included in the "telegraph" equation, are electromagnetic radiation, reflections at insulators, and eddy currents in the line conductors and in the earth wires and earth. Carson‡ has shown that in practical systems the effect of the first is negligible, and a simple calculation shows that the effect of the insulators can also be neglected (save under exceptional conditions at atmospheric pollution and humidity). The effect of eddy currents, neglecting leakage, has been studied by Jacottet§ for the case of a wave of vertical front and infinite length (Heaviside's "Unit" wave) on a simple circuit consisting of two wires remote from earth, or of one wire with earth return. The results he obtains are used as a basis for the following Sections.

(2) SIMPLE SYSTEMS

(a) Waves of unit shape (see Fig. 1)

Jacottet's solution for the shape at a point distant x from the origin of a voltage wave initially of amplitude E and of unit shape is

$$e_x = E\left[1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{\left(t - \frac{x}{v}\right)}}\right]\| \quad . \quad . \quad (1)$$

where e_x = ordinate of the wave at x at time t,
v = velocity of propagation,
and σ = a constant depending only on the line characteristics.

Formulae and typical values for σ are given in Table 3 (see Appendix).

He also shows that on overhead lines v is exactly equal to the velocity of light, irrespective of the nature of the conductors or of the earth. This is due to the fact that the rapidly changing currents involved in travelling waves do not penetrate to an appreciable depth into either the conductors or the earth, so that the circuit inductance is due only to the linkages external to these.

If the origin of time is taken as the instant of arrival of the wave at the point x, equation (1) may be written

$$\frac{e_x}{E} = 1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}} \quad . \quad . \quad . \quad . \quad (2)$$

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† Royal Aircraft Establishment, Hants.

‡ See Reference (1).

‡ See Reference (2).

§ *Ibid.*, (3).

|| $\mathrm{Erf}x = \frac{2}{\sqrt{\pi}}\int_0^x \varepsilon^{-x^2}\,dx$ and is known as the "error function" or the "probability-integral" [see "Elements of Probability," by H. Levy and L. Roth (Clarendon Press, Oxford), for properties and a table of values].

This equation is plotted in Fig. 1 as a curve between e_x/E and $t/(\sigma^2x^2)$, showing that the original vertical-fronted wave is distorted into one having a curved, sloping front, but since

$$\lim_{t\to\infty}\left(\mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right) = 0$$

the ultimate maximum value of the assumed infinite wave is undiminished. This anomalous result is due to the simple approximate formula for the effective circuit resistance employed by Jacottet in his analysis, which, while closely accurate for rapidly changing currents, fails when applied to the infinitely long and more and more slowly rising tail portion of the wave.

Jacottet also extended this solution to include finite rectangular waves, thus removing the anomaly mentioned above, but as such waves seldom occur in practice the results have little useful application. As shown in the Introduction, the important types are chopped waves and waves with exponential tails.

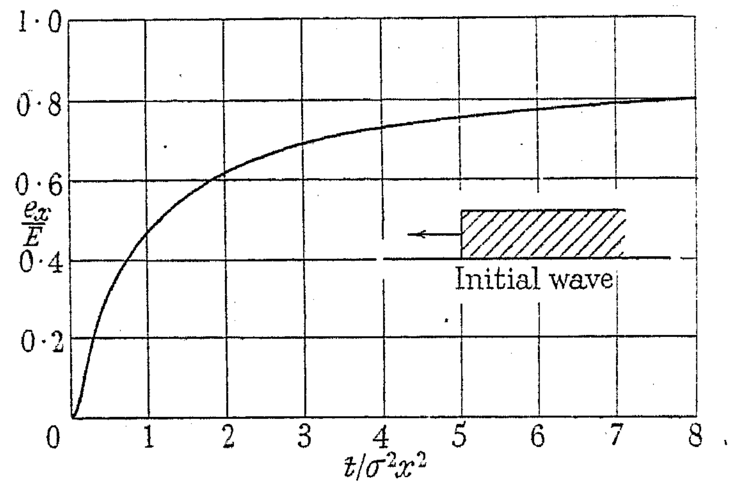

Fig. 1

(b) Chopped waves (see Fig. 2)

Lightning strokes are the principal source of insulator flash-overs on overhead transmission lines, and they are characterized by very steep wave-fronts. On the types of system under consideration, the rate of rise of voltage may be treated as practically constant up to the time of flash-over, whereat the voltage falls suddenly to zero. Thus the wave-shape is triangular as indicated by the initial wave shown in Fig. 2.

If the initial wave-front at $x = 0$ is represented by

$$e_0 = kt$$

then the shape of the wave-front after travelling a distance x is given by the application of Duhamel's theorem to equation (2) as

$$e_x = k\int_0^t\left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt \quad . \quad . \quad . \quad (3)$$

If θ is the duration of the original wave to the flash-over point, then the maximum voltage attained initially is

$$\hat{e}_0 = k\theta$$

and the sudden fall in voltage at $t = \theta$ is equivalent to the addition of a second initial wave

$$e_0 = -kt = -k(t-\theta) - k\theta \text{ for } t > \theta$$

From equations (2) and (3), this second wave becomes at the point x,

$$e_x = -k\int_0^{t-\theta}\left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt - k\theta\left[1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{(t-\theta)}}\right]$$

Hence the total wave for $t > \theta$ is given by

$$\begin{aligned} e_x &= k\int_0^t\left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt \\ &\quad - k\int_0^{t-\theta}\left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt - k\theta\left[1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{(t-\theta)}}\right] \\ &= k\int_{t-\theta}^t\left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt - k\theta\left[1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{(t-\theta)}}\right] \quad (4) \end{aligned}$$

Thus the total wave is given by equation (3) for $0 < t < \theta$ and by equation (4) for $t > \theta$. Using Simpson's rule for integrating, the wave-shape for $\sigma x/\sqrt{\theta} = 0\cdot5$ has been plotted in Fig. 2 and this shows how the wave-front is flattened, the maximum is depressed, and a tail is developed. It is also seen that the maximum value occurs very nearly at $t = \theta$ (actually slightly later), so that to a first approximation the maximum value is obtained by putting the upper limit equal to θ in equation (3), giving

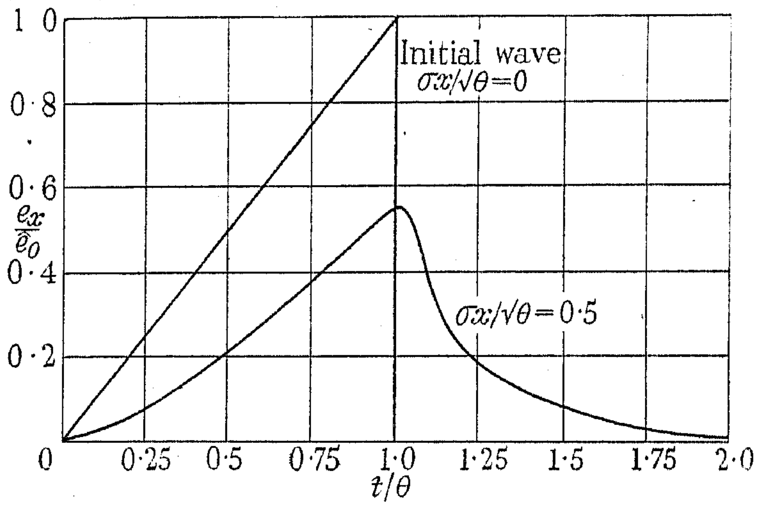

Fig. 2

$$\hat{e}_x = k\int_0^\theta\left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt$$

The original maximum was

$$\hat{e}_0 = k\theta$$

so that the attenuation ratio is

$$\begin{aligned} \frac{\hat{e}_x}{\hat{e}_0} &= \frac{1}{k\theta}\left\{k\int_0^\theta\left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt\right\} \\ &= \frac{\sigma^2x^2}{\theta}\int_0^{\frac{\theta}{\sigma^2x^2}}\left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right)d\left(\frac{t}{\sigma^2x^2}\right) \quad . \quad . \quad (5) \end{aligned}$$

This is a function of $\sigma x/\sqrt{\theta}$ only and its value is plotted in Fig. 3. This is the attenuation curve for chopped voltage waves in a simple system: it is interesting to note that this curve may be extremely well represented by the expression

$$\frac{\hat{e}_x}{\hat{e}_0} = \epsilon^{-1\cdot 2\frac{\sigma x}{\sqrt{\theta}}}$$

over almost the entire range plotted, i.e. the attenuation of chopped waves is very closely exponential. To the scale employed in the Figure, the two curves are indistinguishable.

To assess the order of the numerical values involved, note that the maximum value of a chopped wave is attenuated to one-half when $\sigma x/\sqrt{\theta} = 0\cdot 6$ approximately. Hence, considering a wave between one wire and earth for which σ may be taken as $1\cdot 3 \times 10^{-9}$ (see Appendix), the corresponding distance of travel for a wave, say 4 microseconds in length, is

$$\frac{0\cdot 6 \times \sqrt{(4 \times 10^{-6})}}{1\cdot 3 \times 10^{-9}} = 9\cdot 2 \times 10^5 \text{ cm.} = 5\cdot 7 \text{ miles}$$

The corresponding distances for waves of other lengths are proportional to the square roots of their lengths.

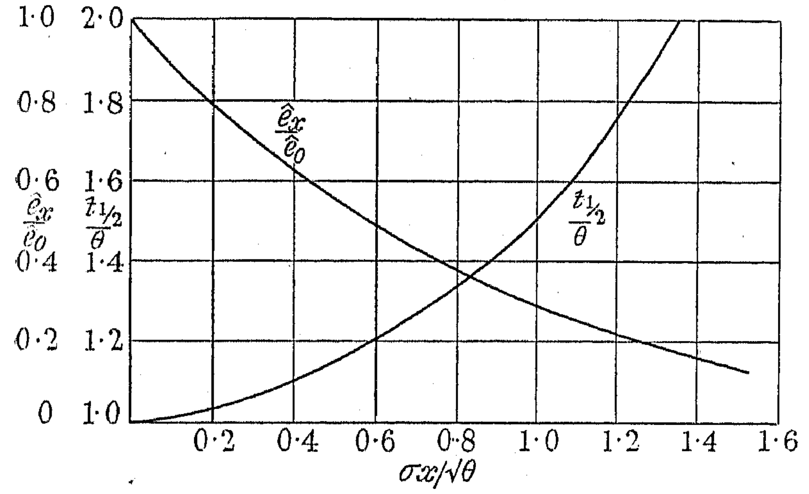

Fig. 3

To obtain the length of the tail of the distorted chopped wave, we may proceed as follows.

The time $t_{\frac{1}{2}}$ at which the tail has died away to half the maximum is given by the solution of the equation made up from equations (4) and (5) thus:—

$$\tfrac{1}{2}k\int_0^{\theta}\left(1 - \operatorname{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt$$

$$= k\int_{t_{\frac{1}{2}} - \theta}^{t_{\frac{1}{2}}}\left(1 - \operatorname{Erf}\frac{\sigma x}{2\sqrt{t}}\right)dt - k\theta\left[1 - \operatorname{Erf}\frac{\sigma x}{2\sqrt{(t_{\frac{1}{2}} - \theta)}}\right]$$

or

$$\tfrac{1}{2}\frac{\sigma^2x^2}{\theta}\int_0^{\frac{\theta}{\sigma^2x^2}}\left(1 - \operatorname{Erf}\frac{\sigma x}{2\sqrt{t}}\right)d\left(\frac{t}{\sigma^2x^2}\right)$$

$$= \frac{\sigma^2x^2}{\theta}\int_{\frac{t_{\frac{1}{2}} - \theta}{\sigma^2x^2}}^{\frac{t_{\frac{1}{2}}}{\sigma^2x^2}}\left(1 - \operatorname{Erf}\frac{\sigma x}{2\sqrt{t}}\right)d\left(\frac{t}{\sigma^2x^2}\right) - \left[1 - \operatorname{Erf}\frac{\sigma x}{2\sqrt{(t_{\frac{1}{2}} - \theta)}}\right]$$

This equation is solved by trial, and values of $t_{\frac{1}{2}}/\theta$ are obtained for various values of $\sigma x/\sqrt{\theta}$; these are plotted in Fig. 3. From this, when a 4-microsecond chopped wave has been attenuated to half value as considered above, it has developed a tail falling to half the maximum in a time such as to make $t_{\frac{1}{2}}/\theta = 1\cdot 2$ or $t_{\frac{1}{2}} = 4\cdot 8$ microseconds, i.e. only $0\cdot 8$ microseconds after the maximum. Thus the tail is still very short even when the wave has been heavily attenuated.

These curves also provide means whereby the past history and original characteristics may be estimated for a chopped wave recorded at some distance from its point of origin. For example, suppose that a 20-kV, 4/5-microsecond wave is recorded on the simple line already considered for which $\sigma = 1\cdot 3 \times 10^{-9}$. For this wave $\theta = 4$ microseconds and $t_{\frac{1}{2}}/\theta = 1\cdot 25$; hence, from Fig. 3, $\sigma x/\sqrt{\theta} = 0\cdot 68$ and the attenuation ratio is $0\cdot 44$. From these,

$$\sigma x = 0\cdot 68\sqrt{(4 \times 10^{-6})} = 1\cdot 36 \times 10^{-3}$$

and

$$x = \frac{1\cdot 36 \times 10^{-3}}{1\cdot 3 \times 10^{-9}} = 1\cdot 045 \times 10^6 \text{ cm.} = 6\cdot 5 \text{ miles}$$

and the original maximum value was

$$\frac{20}{0\cdot 44} = 45 \text{ kV}$$

It has been shown above that chopped waves do not have time to develop very long tails before they are attenuated to negligible amplitudes; hence, since the above calculation depends on the measurement of the interval between a possibly ill-defined maximum and another point not far removed from it, the estimates of past history and distance travelled must not be regarded as precise if they are based on oscillograms which do not permit the accurate location of the necessary points, even when the value of σ for the line is known fairly definitely.

(c) Waves with vertical fronts and exponential tails
(see Fig. 4)

It is now necessary to consider the behaviour of waves having initially the form

$$e_0 = E\epsilon^{-\alpha t} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

It is possible to apply Duhamel's theorem to equations (2) and (6) but the resulting solution is cumbrous. A very close approximation to the required result using simple functions is obtained as follows:—

If the two expressions

$$\frac{e_0}{E} = 1\cdot 53 \operatorname{Erf}\frac{b}{2\sqrt{t}} - 0\cdot 53 \quad . \quad . \quad . \quad (7)$$

and $$\frac{e_0}{E} = \epsilon^{-\frac{4}{3}\cdot\frac{t}{b^2}}$$

are plotted as shown respectively by the full and dotted line curves in Fig. 4, it is found that over a very wide range they closely approach coincidence, so that equation (7) can be used to replace equation (6) if

$$\alpha = \frac{4}{3b^2}$$

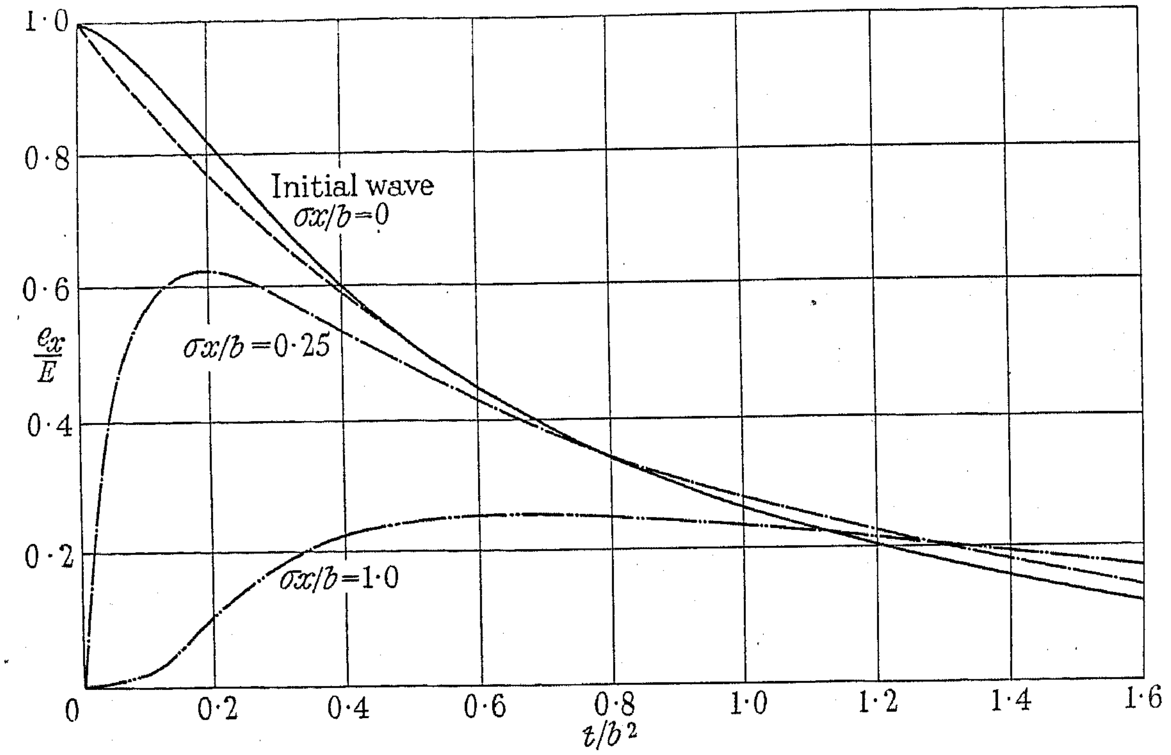

Fig. 4

or, if ϕ is the time for the tail of the original wave to fall to half the maximum,

$$\phi = \frac{\log_\epsilon 2}{\alpha}$$

and
$$b = \frac{2}{\sqrt{(3\alpha)}} = 1\cdot386\sqrt{\phi} \quad . \quad . \quad . \quad (8)$$

The behaviour of a wave of the shape expressed by equation (7) is now easily deduced from equation (2) as follows:—

The wave-shape at the point x_0 of an infinite and initially vertical-fronted wave is given by

$$\frac{e_{x_0}}{E} = 1 - \mathrm{Erf}\,\frac{\sigma x_0}{2\sqrt{t}} \quad . \quad . \quad . \quad . \quad (9)$$

and at $x + x_0$ by

$$\frac{e_{x+x_0}}{E} = 1 - \mathrm{Erf}\frac{\sigma x + \sigma x_0}{2\sqrt{t}} \quad . \quad . \quad . \quad (10)$$

Thus a wave initially of the shape given by equation (9) attains the shape given by equation (10) after travelling a distance x. Now equation (7) may be rewritten

$$\frac{e_0}{E} = 1 - 1\cdot53\left(1 - \mathrm{Erf}\frac{b}{2\sqrt{t}}\right)$$

and hence, from equations (2), (9), and (10), after travelling a distance x this wave becomes

$$\frac{e_x}{E} = \left(1 - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}}\right) - 1\cdot53\left(1 - \mathrm{Erf}\frac{\sigma x + b}{2\sqrt{t}}\right)$$

$$= 1\cdot53\,\mathrm{Erf}\frac{\sigma x + b}{2\sqrt{t}} - \mathrm{Erf}\frac{\sigma x}{2\sqrt{t}} - 0\cdot53 \quad . \quad . \quad (11)$$

This is, to a close degree of approximation, the shape at the point x of a wave originally of the shape given by equation (6).

Equation (11) is plotted for two values of $\sigma x/b$ as chain-dotted curves in Fig. 4, and these show that the original wave has its front flattened, its maximum value reduced, and its tail spread out in a way similar to the chopped wave.

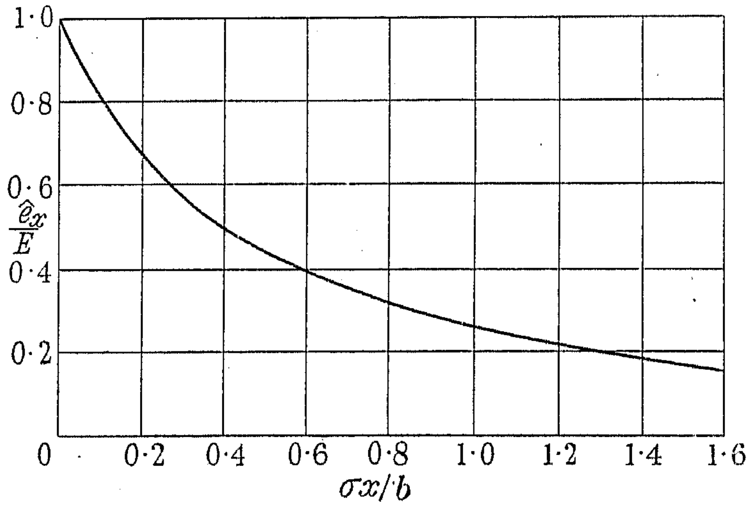

Fig. 5

The maximum value $\hat{e}_x$ of the wave at the point x is found by differentiating the right-hand side of equation (11) and equating to zero: this gives

$$1\cdot53 \times \frac{2}{\sqrt{\pi}}\epsilon^{-\frac{(\sigma x + b)^2}{4t}}\left(-\tfrac{1}{2}\cdot\frac{\sigma x + b}{2t^{3/2}}\right)$$
$$- \frac{2}{\sqrt{\pi}}\epsilon^{-\frac{\sigma^2 x^2}{4t}}\left(-\tfrac{1}{2}\cdot\frac{\sigma x}{2t^{3/2}}\right) = 0$$

whence

$$\frac{t}{b^2}\text{ for maximum} = \frac{t_m}{b^2} = \frac{2\frac{\sigma x}{b} + 1}{4\log_\epsilon\left\{1\cdot53\left(1 + \frac{b}{\sigma x}\right)\right\}} \quad (12)$$

The corresponding values of $\hat{e}_x/E$ are found by substituting these values of t_m/b^2 in equation (11). The results so obtained are plotted in Fig. 5 as a curve between $\hat{e}_x/E$ and $\sigma x/b$. This is the attenuation curve for voltage waves originally of exponential shape.

To assess the numerical order of the quantities involved, consider a 0/20-microsecond wave on a simple line assuming, as before, $\sigma = 1 \cdot 3 \times 10^{-9}$. For this wave

$$b = 1 \cdot 386\sqrt{(20 \times 10^{-6})} = 6 \cdot 2 \times 10^{-3}$$

From Fig. 5, an exponential wave is attenuated to half its original value in a distance such that $\sigma x/b = 0 \cdot 4$ approximately, i.e.

$$x = \frac{0 \cdot 4 \times 6 \cdot 2 \times 10^{-3}}{1 \cdot 3 \times 10^{-9}} = 1 \cdot 9 \times 10^{6} \text{ cm.} = 11 \cdot 8 \text{ miles}$$

As in the case of chopped waves, the corresponding distances for waves of other lengths are proportional to b, i.e. to the square roots of the lengths of the waves.

(d) Extension to waves with finite fronts

By successive approximations, the value of t/b^2 for a point on the tail of a wave given by equation (11) where the voltage is equal to half the maximum can be obtained for various values of $\sigma x/b$; if this be called $t_{\frac{1}{2}}/b^2$, then division gives

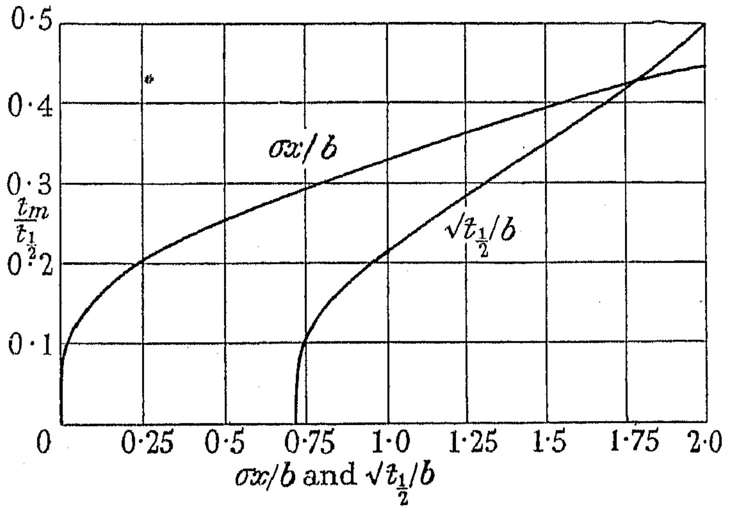

Fig. 6

$$\frac{t_m}{b^2} \div \frac{t_{\frac{1}{2}}}{b^2} = \frac{t_m}{t_{\frac{1}{2}}}$$

In Fig. 6, $\sqrt{t_{\frac{1}{2}}}/b$ is plotted against $t_m/t_{\frac{1}{2}}$ and so also are the corresponding values of $\sigma x/b$. These curves now permit the values of b and σx to be found corresponding to a wave of any length of front and tail. For example, suppose that an incident wave has a peak value of 50 kV and a shape 5/20-microseconds: for this $t_m/t_{\frac{1}{2}} = 5/20 = 0 \cdot 25$, whence, from Fig. 6, $\sigma x/b = 0 \cdot 5$ and $\sqrt{t_{\frac{1}{2}}}/b = 1 \cdot 12$. From these

$$b = \frac{\sqrt{(20 \times 10^{-6})}}{1 \cdot 12} = 4 \times 10^{-3}$$

and $\qquad \sigma x = 0 \cdot 5 \times 4 \times 10^{-3} = 2 \times 10^{-3}$

This wave can now be treated as if it had originally had a vertical front and exponential tail but had started from a point distant x back along the line. From Fig. 5 the attenuation ratio for $\sigma x/b = 0 \cdot 5$ is $0 \cdot 43$, so that it would have had a maximum value of $50/0 \cdot 43 = 116$ kV and a tail falling to half value in

$$\left(\frac{4 \times 10^{-3}}{1 \cdot 386}\right)^2 = 8 \cdot 3 \text{ microseconds}$$

If σ is again assumed to be $1 \cdot 3 \times 10^{-9}$

$$x = \frac{2 \times 10^{-3}}{1 \cdot 3 \times 10^{-9}} = 1 \cdot 54 \times 10^{6} \text{ cm.} = 9 \cdot 6 \text{ miles}$$

The behaviour of the real incident wave can now be calculated for any point along the line. For example, at a point 10 miles down the line x has increased to 19·6 miles = $3 \cdot 15 \times 10^{6}$ cm., giving a value of

$$\frac{\sigma x}{b} = \frac{1 \cdot 3 \times 10^{-9} \times 3 \cdot 15 \times 10^{6}}{4 \times 10^{-3}} = 1 \cdot 02$$

From Figs. 5 and 6 the following values are obtained: Attenuation ratio $= 0 \cdot 25$, $t_m/t_{\frac{1}{2}} = 0 \cdot 33$, and $\sqrt{t_{\frac{1}{2}}}/b = 1 \cdot 43$, giving a maximum value of $0 \cdot 25 \times 116 = 29$ kV, $t_{\frac{1}{2}} = (1 \cdot 43 \times 4 \times 10^{-3})^2 = 33$ microseconds, and $t_m = 33 \times 0 \cdot 33 = 11$ microseconds, so that after travelling 10 miles the original 50-kV, 5/20-microsecond wave becomes a 29-kV, 11/33-microsecond wave.

If the wave considered were not the incident wave, but were simply a record taken at some point on the line, then the data obtained for the possible original exponential wave give an upper limit for the amplitude and distance away of the original wave. For example, if the 50-kV, 5/20-microsecond wave were recorded, the curves show that it could not have originated more than 9·6 miles away and could not have had a peak value of more than 116 kV or a tail of more than 8·3 microseconds to half value.

It will be noted from Fig. 6 that for values of $t_m/t_{\frac{1}{2}}$ up to 0·1 we may write, to a close degree of approximation,

$$\frac{\sigma x}{b} = 0, \ \frac{\sqrt{t_{\frac{1}{2}}}}{b} = 0 \cdot 722, \text{ and } b = 1 \cdot 386\sqrt{t_{\frac{1}{2}}}$$

These results show that waves whose lengths of front do not exceed one-tenth of their lengths to half maximum on the tail may be treated as vertical-fronted waves for the purpose of calculating the attention and distortion. They also show that the front of an initially vertical-fronted wave is flattened very rapidly indeed down to approximately one-tenth of the tail length to half maximum, but thereafter the flattening is much slower.

Finally, they show that if a wave be recorded whose front is shorter than one-tenth of its tail length to half maximum, then the distance to the point of origin is very short indeed, i.e. within a few hundred feet.

(3) PRACTICAL POWER TRANSMISSION SYSTEMS

(a) Subdivision of waves (without earth wires)

When waves on practical power systems are considered, the above simple procedure requires modification owing to the fact that waves are induced in all the remaining conductors besides those carrying the main waves. These induced waves travel at the same speed as the main waves, and their presence causes a modification in the type and rate of attenuation and distortion experienced by the main waves. By an analysis similar to the well-known method of symmetrical components, Bekku* has shown that on a symmetrical, completely transposed, three-phase overhead transmission line supported at a finite distance above the earth and without an earth wire, the waves on the three lines may be split up into two groups, viz.:—

Group A:—Three waves identical on all three lines.
Group B:—Three waves whose sum is zero.

Table 1

Impact on	Proportion in Group A (all lines)		Proportion in Group B			
			Three-phase		Single-phase	
	Three-phase	Single-phase	Lines struck	Lines not struck	Lines struck	Lines not struck
1 line	m	m	$1 - m$	$-\frac{1}{2}(1 - m)$	$1 - m$	$-(1 - m)$
2 lines	m	1	$1 - m$	$-2(1 - m)$	0	0
3 lines	1	—	0	0	—	—

The proportions of the total waves falling into each of these depend on the relative effective line impedances for the two groups and on whether the original wave was incident upon one, two, or three lines. This analysis may also be applied to a single-phase transmission line having only two wires, the two groups now being as follows:—

Group A:—Two waves identical on both lines.
Group B:—Two waves whose sum is zero.

Table 1 shows the proportions of the voltage waves in each group in terms of m, the ratio of the Group A wave to the incident wave on the line or lines struck.

Formulae and representative values for the line impedances, and the resulting values of m, are given in Table 3 (see Appendix).

Examination of the values of σ given in the Appendix shows that the rate of attenuation of Group A waves is many times more rapid than that of Group B. Hence to a first approximation the wave at a point may be written as the sum of the distorted and attenuated Group A wave and the unaffected Group B wave. For impacts on one line of a single-phase system and on one or two lines in a three-phase system, this results in the preservation of part of the original wave-front. Further, owing to the negative sign of the Group B waves on the untouched lines, the total waves in these lines, which are purely induced waves, develop a negative loop preceding the positive parts of their fronts.

(b) Chopped waves

From the above considerations and from equation (5), it is evident that the maximum value of the total wave at a point x on the line struck, due to an impact causing a chopped wave at the origin, is given by

$$\frac{\hat{e}_x}{\hat{e}_0} = (1 - m) + m\frac{\sigma^2 x^2}{\theta}\int_0^{\frac{\theta}{\sigma^2 x^2}}\left(1 - \operatorname{Erf}\frac{\sigma x}{2\sqrt{t}}\right)d\left(\frac{t}{\sigma^2 x^2}\right) \qquad (13)$$

where σ is calculated for Group A waves.

This expression is plotted in Fig. 7 for values of m between 0·4 and 1·0, and these curves are the attenuation curves for chopped voltage waves on single- and three-phase systems. Taking $m = 0{\cdot}6$ for a wave on one line, the curves show that the distance required to attenuate a chopped wave to half its original maximum value, as compared with that required on a single wire parallel to the earth, is increased in the ratio $1{\cdot}4/0{\cdot}6 = 2{\cdot}3$ times (approximately).

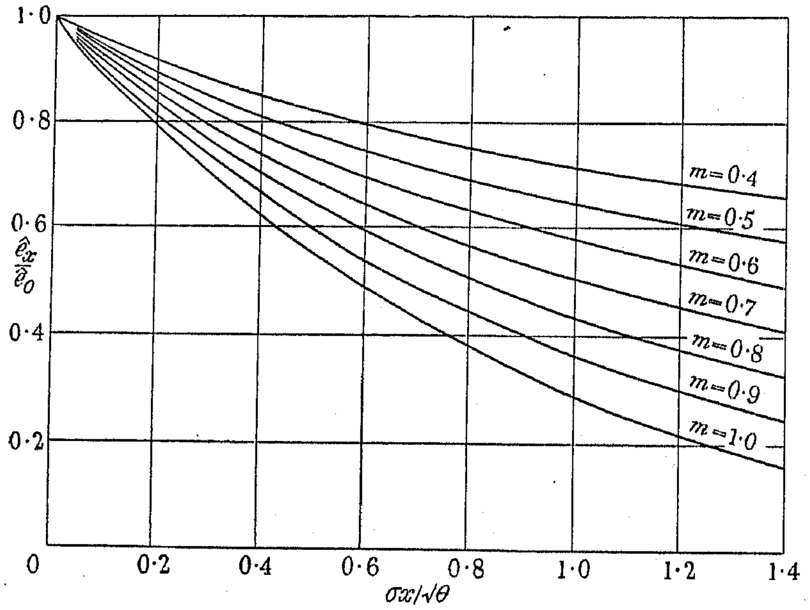

Fig. 7

(c) Waves with vertical fronts and exponential tails

In the same way as above, the total wave at a point x on the line or lines struck and carrying a wave of this type is obtained from equations (7) and (11) as

$$\frac{e_x}{E} = (1 - m)\left(1{\cdot}53\operatorname{Erf}\frac{b}{2\sqrt{t}} - 0{\cdot}53\right) + m\left(1{\cdot}53\operatorname{Erf}\frac{\sigma x + b}{2\sqrt{t}} - \operatorname{Erf}\frac{\sigma x}{2\sqrt{t}} - 0{\cdot}53\right) \qquad (14)$$

where σ is calculated for Group A waves.

This wave has a vertical portion to its front equal to $(1 - m)E$. The maximum value $\hat{e}_x/E$ is found by differ-

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* See Reference (4).

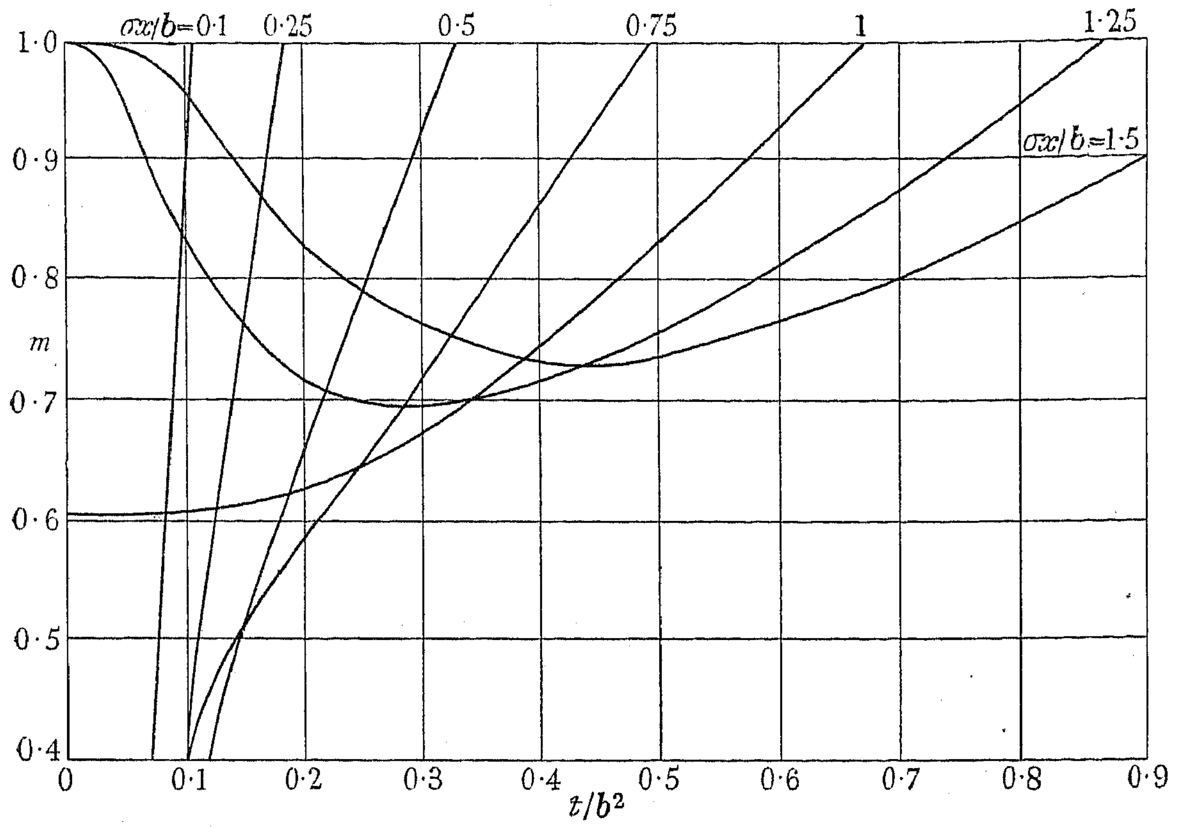

Fig. 8

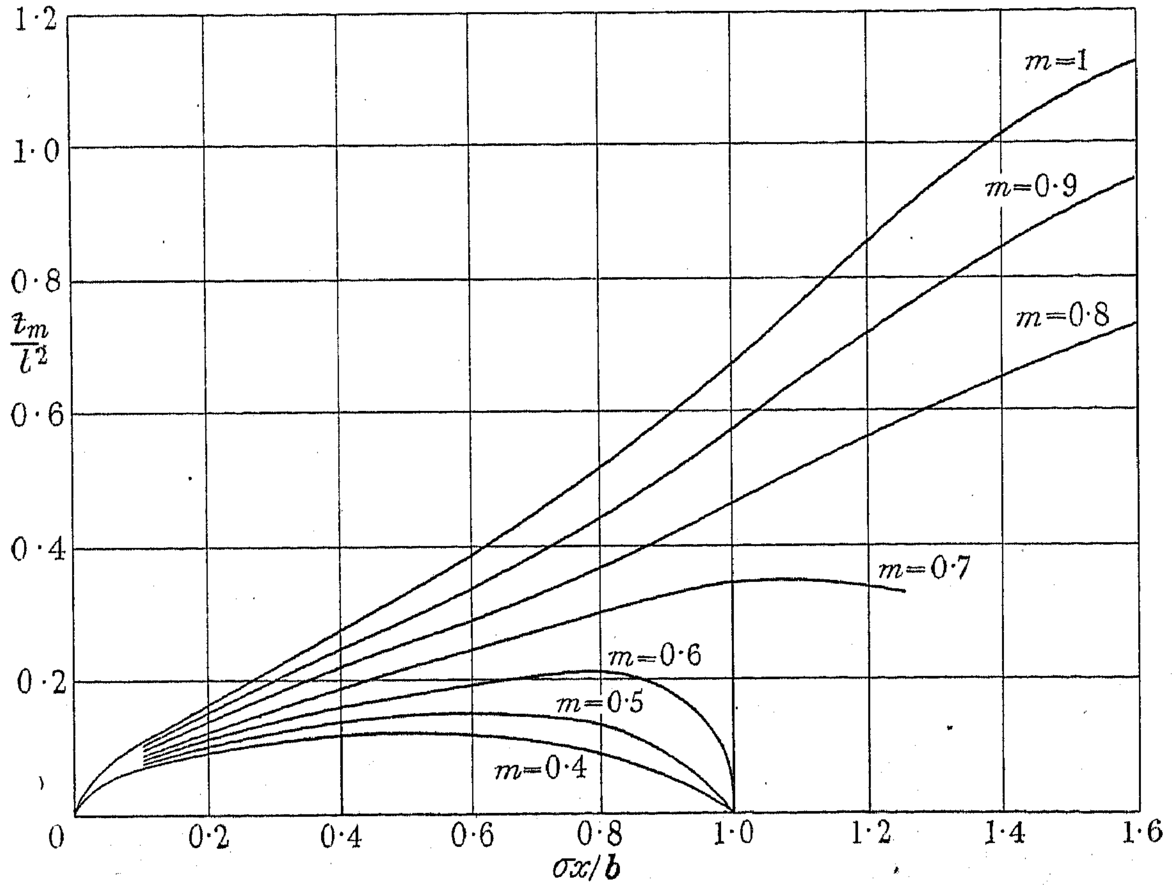

Fig. 9

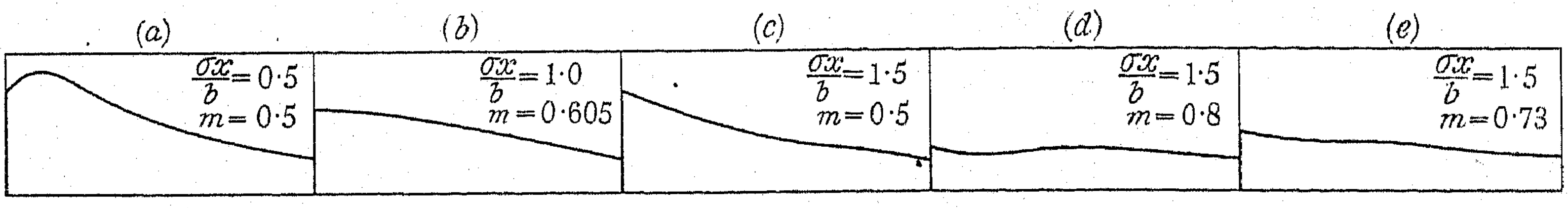

Fig. 10

(a) Maximum at $t/b^2 = 0\cdot15$; (b) Point of inflexion at $t/b^2 = 0$; (c) Maximum at $t/b^2 = 0$; (d) Maxima at $t/b^2 = 0$ and $0\cdot7$, minimum at $t/b^2 = 0\cdot24$; (e) Maximum at $t/b^2 = 0$, point of inflexion at $t/b^2 = 0\cdot45$.

entiating the right-hand side of equation (14) with respect to t and equating to zero. This gives

$$\frac{2}{\sqrt{\pi}}\times 1\cdot 53(1-m)\epsilon^{-\frac{b^2}{4t}}\left(-\frac{b}{4t^{3/2}}\right)+\frac{2}{\sqrt{\pi}}\times 1\cdot 53m\epsilon^{-\frac{(\sigma x+b)^2}{4t}}\left(-\frac{\sigma x+b}{4t^{3/2}}\right)-\frac{2}{\sqrt{\pi}}m\epsilon^{-\frac{\sigma^2x^2}{4t}}\left(-\frac{\sigma x}{4t^{3/2}}\right)=0$$

i.e.

$$\frac{1-m}{m}=0\cdot 654\frac{\sigma x}{b}\epsilon^{-\frac{\frac{\sigma^2x^2}{b^2}-1}{4t/b^2}}-\left(1+\frac{\sigma x}{b}\right)\epsilon^{-\frac{\frac{\sigma x}{b}\left(2+\frac{\sigma x}{b}\right)}{4t/b^2}} \qquad (15)$$

By assigning values to $\sigma x/b$ and t/b^2, values of m may be calculated. Curves of these results are given in Fig. 8, and from these, for selected constant values of m, the values of t/b^2 for maximum $= t_m/b^2$ are read off; these are plotted against $\sigma x/b$ in Fig. 9 for values of m from $0\cdot 4$ to $1\cdot 0$.

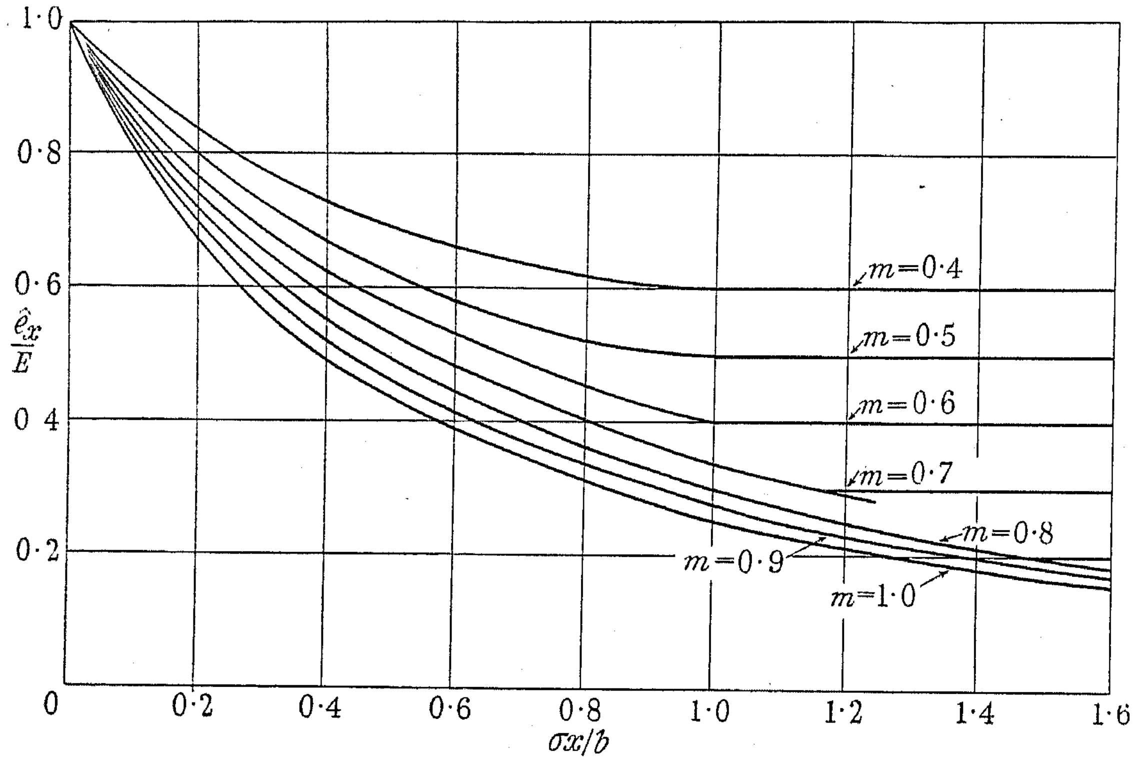

Fig. 11

Figs. 8 and 9 show that for $\sigma x/b < 1$ there is a maximum which is greater than the vertical part of the front, $(1-m)E$. For $\sigma x/b > 1$ there is a minimum and a maximum provided that m is large enough, i.e. after the initial vertical rise the wave dips and rises again, but if m is too small there is no maximum and the initial rise is the highest point on the wave. For values of m corresponding to the lowest points on the curves in Fig. 8 for $\sigma x/b > 1$, there is a point of inflexion on the wave tail. For $\sigma x/b = 1$ and $m = 0\cdot 605$, this point of inflexion occurs at $t/b^2 = 0$, and the wave is initially flat-topped. These types of wave are illustrated in Fig. 10. The curves in Fig. 9 for values of $m > 0\cdot 605$ have *points d'arrêt* corresponding to these points of inflexion.

By inserting the values of t_m/b^2 obtained from Fig. 9 in equation (14), the corresponding maximum values of $\hat{e}_x/E$ are obtained. These are plotted in Fig. 11 for values of m from $0\cdot 4$ to $1\cdot 0$. For values of $m > 0\cdot 605$, the lower portions of these curves have two branches corresponding to the initial peak and the subsequent maximum. The lower of these branches have *points d'arrêt* where the corresponding maxima degenerate into points of inflexion. These are the attenuation curves for voltage waves on single- and three-phase systems, and it will be noted that these are not uniformly spaced as was the case with chopped waves, but the curves for the higher values of m are crowded more closely together.

(d) Waves with finite fronts and estimates of past history of waves

It is possible to extend the above analysis to include the case of waves with finite fronts, but the general formulae become unwieldy, and to cover all cases a large number of sets of curves would be required. However, as indicated in Section 2(*d*), waves whose lengths of front do not exceed one-tenth of their tail lengths to half value may be treated as vertical-fronted waves for the purpose of calculating the attenuation and distortion, so that the results developed in the above Section are applicable to waves of this type.

In the same way, it is impracticable to provide general curves to estimate the past history and future behaviour of waves recorded at some point on the line distant from the point of incidence.

It is necessary in such cases to treat each instance on its own merits, except for strokes to three lines simultaneously, when, since the Group B waves are zero, the results obtained for simple systems are applicable.

In the case of chopped waves, it is evident from Fig. 2 that the combination of the distorted and attenuated Group A waves and the unmodified Group B waves yield total waves not differing greatly in shape from the Group A wave, the principal difference being a vertical drop after the peak. In practice this will merge imperceptibly into the tail of the Group A wave, and the effect will be to produce a wave having a very short length of tail to half maximum value, thus accentuating to a prohibitive extent the difficulty and the danger of inaccuracy

Table 2

EFFECT OF NON-MAGNETIC EARTH WIRES

Impact on	Distorted components (all lines)		Undistorted component			
			Three-phase		Single-phase	
	Three-phase	Single-phase	Lines struck	Lines not struck	Lines struck	Lines not struck
1 line ..	$(1-q)m$	$(1-q)m$	$1-(1-q)m$	$-\frac{1}{2}\{1-(1+2q)m\}$	$1-(1-q)m$	$-\{1-(1+q)m\}$
2 lines ..	$(1-q)m$	$1-q$	$1-(1-q)m$	$-2\{1-(1+\frac{1}{2}q)m\}$	q	—
3 lines ..	$1-q$	—	q	—	—	—

mentioned in Section 2(*b*). This increase in difficulty does not arise, however, where the chopped wave occurs on all lines simultaneously, since the Group B waves are zero. This case has a distinct probability in practice, since lightning strokes frequently involve all lines, causing the line insulators to flash over simultaneously.

(e) Effect of earth wires

When a set of continuously earthed conductors is mounted parallel to the line wires, the value of Z_A (see Table 3 in the Appendix) is reduced, and thus m is also reduced. In addition to this, however, the Group A waves now require subdivision as follows:—

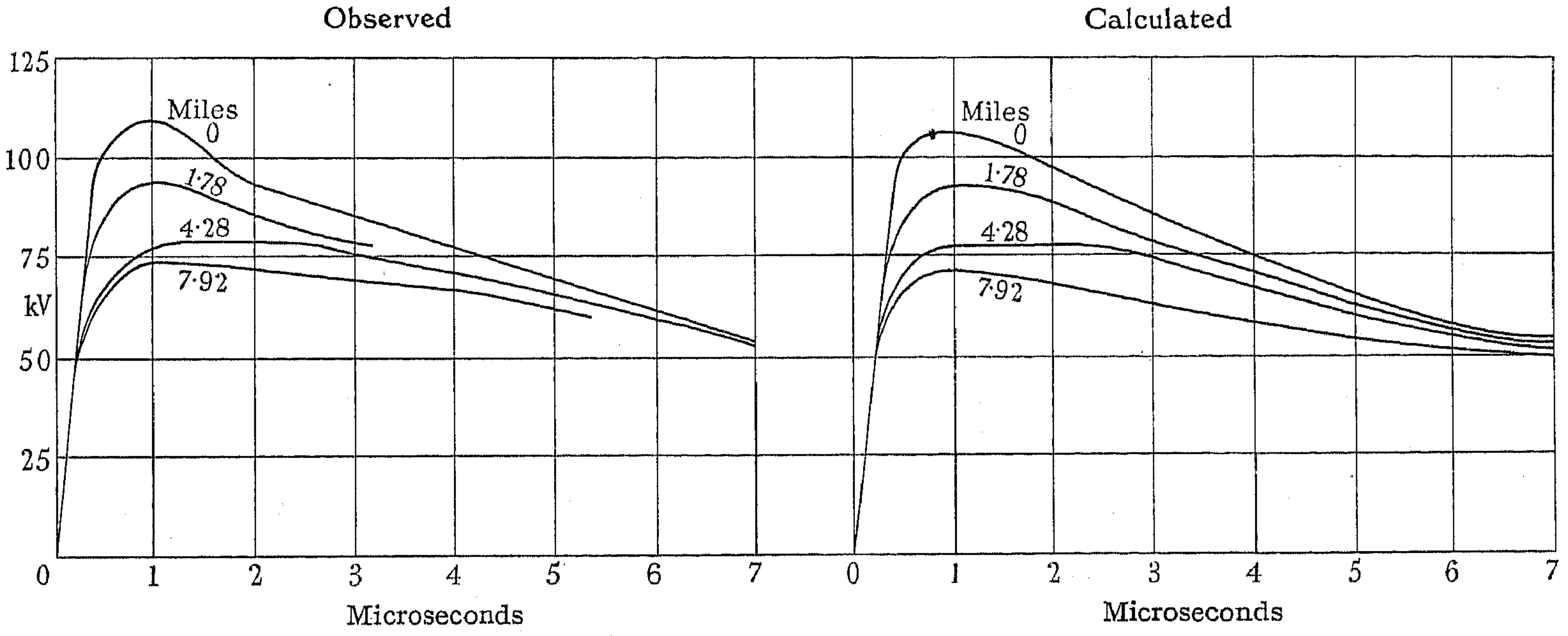

Fig. 12

Group A_1. Waves travelling between all conductors in parallel and earth.

Group A_2. Waves travelling between all conductors in parallel and all earth wires in parallel.

The behaviour of the Group A_1 waves is identical with that of the Group A waves already considered, but that of the Group A_2 waves depends on the nature of the material used for the earth wires. If this is non-magnetic, then these waves are only very slowly attenuated and distorted, and they behave exactly like Group B waves. If, however, a magnetic material is used, then, as shown by the values of σ given in Table 3, the behaviour of the Group A_2 waves is closely similar to that of the Group A_1 waves, and no serious error is introduced by neglecting any difference and treating them as one set of waves. That is to say, having made due allowance in the calculation of the values of Z_A and m for the presence of the earth wires, the method given in Sections 3[(*a*) to (*d*)] can be applied immediately.

In the case of the non-magnetic earth wires, it is necessary to proceed as follows:—

Suppose that the proportion of the Group A waves which falls into Group A_2 is q, then on the conductors on which the main waves are travelling the component waves [see Table 1 in Section 3(*a*)] and the total distorted and undistorted components are as shown below:—

$$\text{Group A}: m \begin{cases} \text{Group A}_1: (1-q)m: \text{ distorted.} \\ \text{Group A}_2: qm \end{cases}$$
$$\left.\begin{matrix} \text{Group A}_2: qm \\ \text{Group B}: (1-m) \end{matrix}\right\rangle 1-(1-q)m: \text{ undistorted.}$$

The net effect of this is to cause the waves on these conductors to behave as if the line had no earth wires but had its m value changed to $(1-q)m$, i.e. the effective value of m is reduced. Similar remarks apply to the waves induced in the other conductors, but the modification to the effective value of m is different.

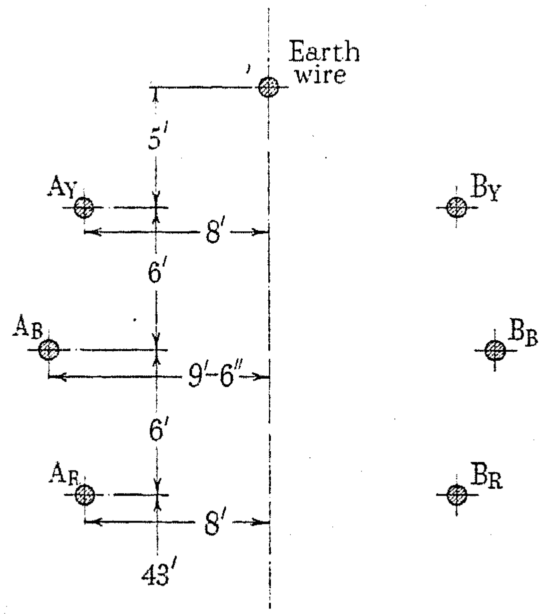

Fig. 13

With impacts on all lines, subdivision into distorted and undistorted components still exists, and the above considerations still apply save that m is now equal to 1.

The results of the application of the above to single- and three-phase transmission lines are given in Table 2.

The effects of earth wires may be summarized as follows:

(*a*) With earth wires of magnetic material, the behaviour of the waves is as calculated by the method of Section 3(*a*), using appropriate values of Z_{Δ} and m.

(*b*) With earth wires of non-magnetic material, the behaviour of the waves is as in Table 2 in which the effective value of m is modified by additional terms.*

(f) Comparison with experimental results

To check the formulae and curves developed in the preceding Sections, they have been applied to some oscillograms taken on representative transmission lines.

In Fig. 12, oscillograms taken by Hawley and Lacey† are given on the left-hand side. The initial wave had a 1/7-microsecond shape and was injected on one conductor of a two-circuit, three-phase, 33-kV overhead transmission line fitted with one earth wire of non-magnetic material. The line was a Central Electricity Board line in Somerset, and the configuration of the conductors was as shown in Fig. 13. Oscillograms of the wave-shape at

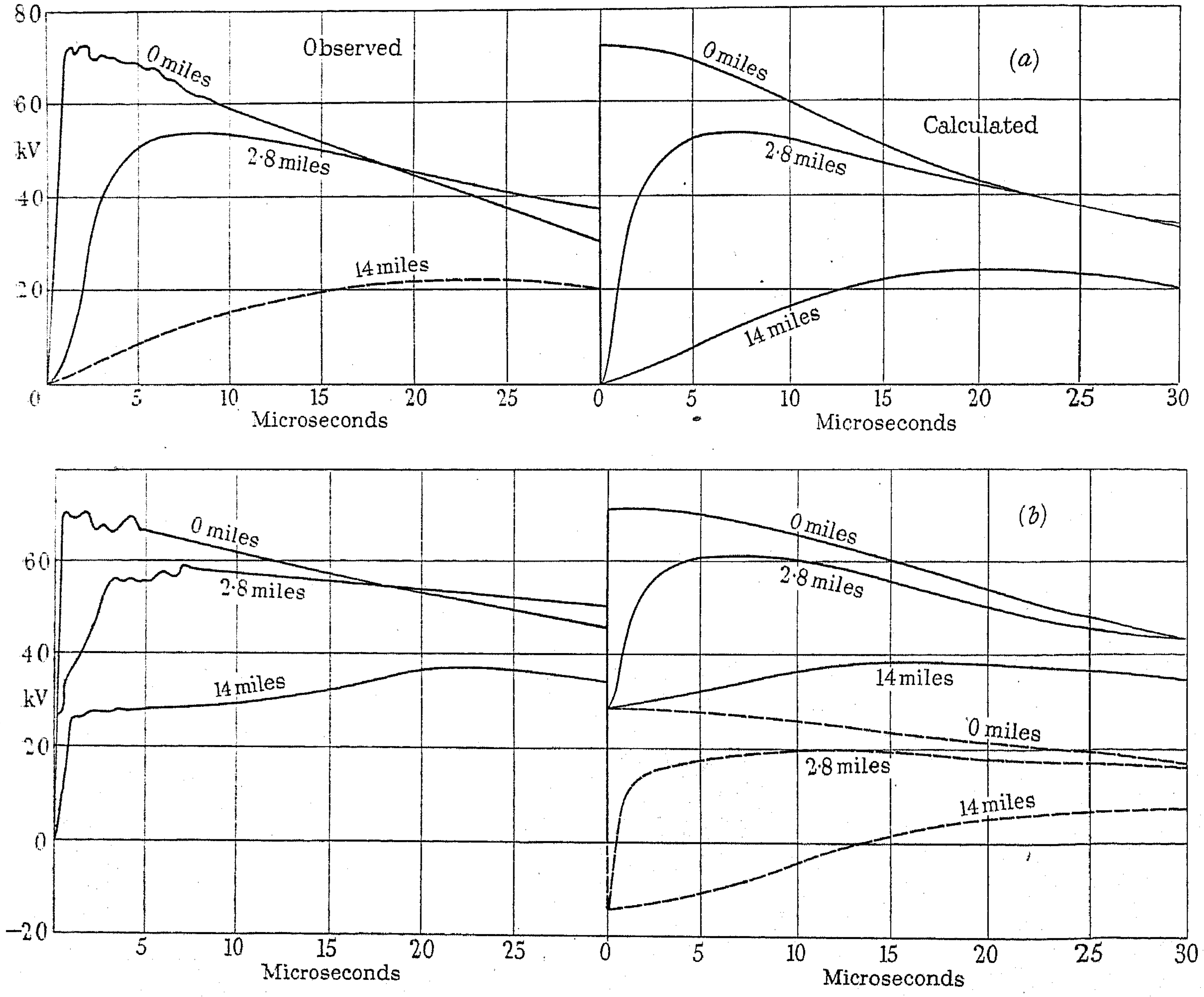

Fig. 14

(*a*) Wave on 3 lines. (*b*) Wave on 1 line.

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* Note that, under certain circumstances, the undistorted component of the induced waves can vanish, e.g. for impact on one conductor of a three-phase line this occurs when $m = 1/(1 + 2q)$.

† See Reference (5).

three points out on the line were taken at distances as indicated in the Figure. Since the earth wire was non-magnetic, Table 2 applies, and an examination of the oscillograms shows that an approximate value for $(1 - q)m$ is $0\cdot35$. Using this value and taking $\sigma = 2\cdot3 \times 10^{-9}$ (see Table 3), the wave-shapes shown on the right of Fig. 12 have been calculated by the methods of Sections 2(*d*) and 3(*d*). The agreement between the calculated and the experimental results is seen to be extremely close.

As a further check, the formulae, etc., have been applied to some oscillograms taken by Brune and Eaton.* These are reproduced on the left-hand side of Fig. 14.† Of these, the upper set is for a wave travelling on all three lines, and the lower set is for a wave on one line only.

No data are given for the characteristics of the line tested, but since there is no residue of the original wave-front in the oscillograms for waves on three lines, $q = 0$ (see Table 2). Also, from the height of the nearly vertical portion of the wave-front in the oscillogram for the one-line wave, it is found that $m = 0\cdot6$ approximately. The original waves for the two cases can be approximately described as 72-kV, 0/25-microseconds, and 72-kV, 0/40-microseconds, respectively. Using these initial values and assuming, as in the previous instance, that $\sigma = 2\cdot3 \times 10^{-9}$, the wave-shapes shown on the right-hand side of Fig. 14 are obtained and their agreement with the experimental results is seen to be very close. The corresponding induced waves on the untouched conductors in the case of the wave on one line have been calculated in order to show the formation of the negative loop described in Section 3(*a*): these are shown dotted on the right-hand side of Fig. 14.

(4) CONCLUSION

Formulae and curves have been developed which permit the calculation of the behaviour of two of the most important types of natural disturbances occurring in single- and three-phase overhead power transmission systems, and the close agreement with some experimental results is good confirmation of their utility and accuracy.

Subject to certain limitations, the methods developed are reversible and make possible the estimation of limiting values for the distance travelled and the original amplitudes and shapes of wave recorded at points remote from their sources.

The author wishes to thank the Director of the British Electrical and Allied Industries Research Association for permission to reproduce the data in Figs. 12 and 13.

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APPENDIX

Formulae and representative values for σ and m.
List of symbols and assumed values.

(1) *Simple systems.*

(*a*) *Isolated two-wire.* *Assumed values.*
a = radius of each wire, in cm. = 0·5
d = distance between wires, in cm. = 100
ρ = specific resistance of material of wires, in ohms/cm. cube = $1\cdot7 \times 10^{-6}$

(*b*) *One wire and earth.*
a = radius of wire, in cm. = 0·5
h = height of wire above earth, in cm. = 1 000
ρ' = specific resistance of the earth, in ohms/cm. cube = 5 000

(*c*) *Isolated two-wire with one wire of magnetic material.*
a = radius of non-magnetic wire, in cm. = 0·5
a_s = radius of magnetic wire, in cm. = 0·3
d = distance between wires, in cm. = 100
ρ_s = specific resistance of magnetic wire, in ohms/cm. cube = $8\cdot8 \times 10^{-6}$
μ = permeability of magnetic wire = 300*

(2) *Practical systems (without earth wires and completely transposed).*

(*a*) *Single-phase.*
a = radius of each wire, in cm. = 0·5
d = average distance between wires, in cm. = 100
h = average height of wires above earth, in cm. = 1 000
ρ = specific resistance of material of wires, in ohms/cm. cube = $1\cdot7 \times 10^{-6}$
ρ' = specific resistance of the earth, in ohms/cm. cube = 5 000

(*b*) *Three-phase.*
Symbols as above.

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* See Reference (6).

† An error of 2 seems to have occurred in the scaling of the oscillogram shown dotted. In the original paper, the ordinates given are scaled at twice the values shown. In view of the excellent agreement obtained with all the remaining oscillograms, the presence of an error seems probable.

* The value to be used for μ is very indefinite. The surge currents may reach magnitudes in excess of 20 000 amperes, even after travelling a considerable distance along the line, and saturation may occur at the crest of the wave. The value of 300 is taken only as a very rough approximation for the purpose of making a reasonable estimate of the attenuation obtained in practice.

Table 3

FORMULAE

Item	Wave distribution	$\dfrac{\sigma}{6{\cdot}46 \times 10^{-8}}$	Surge impedance Z (ohms)	m for impact on: One line	m for impact on: Two lines	m for impact on: Three lines
I(a)	—	$\dfrac{\sqrt{\rho}}{a \log_{10} \dfrac{d}{a}}$	$276 \log_{10} \dfrac{d}{a}$	—	—	—
I(b)*	—	$\dfrac{\sqrt{\rho'}}{h \log_{10} \dfrac{2h}{a}}$	$138 \log_{10} \dfrac{2h}{a}$	—	—	—
I(c)*	—	$\dfrac{\sqrt{(\mu\rho_s)}}{2a_s \log_{10} \dfrac{d}{\sqrt{(aa_s)}}}$	$276 \log_{10} \dfrac{d}{\sqrt{(aa_s)}}$	—	—	—
II(a)	Group B; wire/wire	$\dfrac{\sqrt{\rho}}{a \log_{10} \dfrac{d}{a}}$	$Z_B = 138 \log_{10} \dfrac{d}{a}$	$\dfrac{Z_A}{Z_A + Z_B}$	1	—
	Group A; 2 wires/earth	$\dfrac{\sqrt{\rho'}}{h \log_{10} \dfrac{2h}{\sqrt{(ad)}}}$	$Z_A = 138 \log_{10} \dfrac{4h^2}{ad}$			
II(b)	Group B; wire/2 wires	$\dfrac{\sqrt{\rho}}{a \log_{10} \dfrac{d}{a}}$	$Z_B = 138 \log_{10} \dfrac{d}{a}$	$\dfrac{Z_A}{Z_A + 2Z_B}$	$\dfrac{2Z_A}{2Z_A + Z_B}$	1
	Group A; 3 wires/earth	$\dfrac{\sqrt{\rho'}}{h \log_{10} \dfrac{2h}{(\sqrt[3]{ad^2})}}$	$Z_A = 138 \log_{10} \dfrac{8h^3}{ad^2}$			

Representative values calculated from above assumed data

I(a)	—	$\sigma = 7{\cdot}32 \times 10^{-11}$	$Z = 635$	—	—	—
I(b)	—	$\sigma = 1{\cdot}27 \times 10^{-9}$	$Z = 497$	—	—	—
I(c)	—	$\sigma = 2{\cdot}29 \times 10^{-9}$	$Z = 665$	—	—	—
II(a)	Group B; wire/wire	$\sigma = 7{\cdot}32 \times 10^{-11}$	$Z_B = 317$	0·68	1	—
	Group A; 2 wires/earth	$\sigma = 1{\cdot}86 \times 10^{-9}$	$Z_A = 676$			
II(b)	Group B; wire/2 wires	$\sigma = 7{\cdot}32 \times 10^{-11}$	$Z_B = 317$	0·575	0·844	1
	Group A; 3 wires/earth	$\sigma = 2{\cdot}21 \times 10^{-9}$	$Z_A = 855$			

* The contribution of the line conductor to the value of σ is negligible as compared with that due to the earth or the magnetic wire.

FLUCTUATION NOISE IN PARTIALLY SATURATED DIODES*

By D. A. BELL, B.A., B.Sc., Graduate.

(*Paper first received* 26*th May, and in revised form* 18*th November,* 1938.)

SUMMARY

A previous paper† discussed the nature of fluctuation noise in thermionic valves which are either perfectly temperature-limited or perfectly space-charge-limited. It was suggested that the noise should be represented by a "shot noise" formula in the former, and a "thermal noise" formula in the latter. But since perfection is difficult to achieve, the case of more practical value is the valve which is mainly space-charge-limited, but not entirely free from temperature limitation. A method of quantitative estimation of the noise in diodes under such conditions (in terms of the current/voltage characteristic) is the subject of this further paper.

The "ideal" diode would have a characteristic such as that sketched in Fig. 1, curve (*a*), following a $\frac{3}{2}$-power law from the origin to a point $V_a = V_s$, and then changing abruptly to constant current. In an actual valve, however, the curve is more likely to be as shown by the dotted line (*b*), where the current is not zero at $V_a = 0$ (owing to electron emission velocity). The slope of the curve is always less than corresponds to the $\frac{3}{2}$-power law, and the change to temperature-limitation (constant-current condition) is comparatively gradual. From the previous paper we have hypotheses which would permit us to predict the noise from the i_a/V_a characteristic for both parts of curve (*a*); namely, as thermal noise in a certain equivalent resistance at a defined effective temperature for the $\frac{3}{2}$-power law (space-charge-limited) region, and as simple shot noise for the constant-current (temperature-limited) region. But we have to face the problem of curve (*b*), which does not belong wholly to either of these regions.

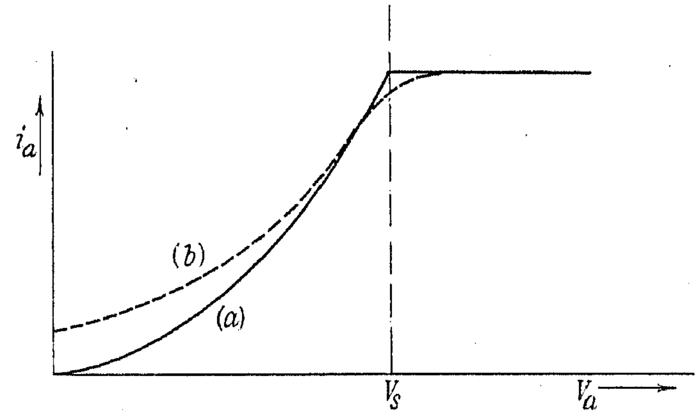

Fig. 1

Consider now a hypothetical system of two diodes of identical construction but different cathode temperatures, one of which, (*a*), is perfectly space-charge-limited, while the other, (*b*), is perfectly temperature-limited throughout the range of anode voltage chosen for examination. The temperature-limitation of (*b*) is suggested in Fig. 2 by the resistance in series with its heater, giving a lower cathode temperature and less emission. The currents in the two valves are accordingly given by the expressions

$$i_1 = aV_a^{3/2} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$i_2 = b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and the total current i_0 will be

$$i_0 = i_1 + i_2 = aV_a^{3/2} + b \quad . \quad . \quad . \quad (3)$$

Now suppose it is impossible to measure separately the currents i_1 and i_2; it will still be possible to determine them from a series of observations of i_0 at different values of V_a, by making use of the slope of the i_0/V_a characteristic. Thus

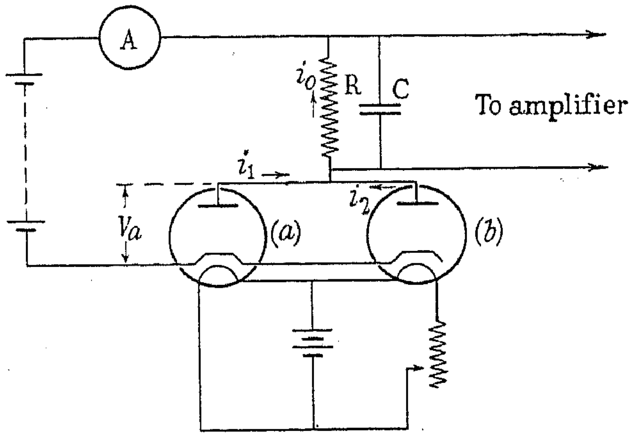

Fig. 2

$$\frac{di_0}{dV_a} = (3/2)aV_a^{\frac{1}{2}} = \frac{3i_1}{2V_a}$$

$$\therefore \quad i_1 = \frac{2V_a}{3} \cdot \frac{di_0}{dV_a} = \frac{2V_a}{3R_a} \quad . \quad . \quad . \quad (4)$$

In fact the measurable slope conductance di_0/dV_a of the combination is equal to that of valve (*a*) alone, since valve (*b*) has zero slope conductance. By simple subtraction we then write

$$i_2 = i_0 - i_1 = i_0 - \frac{2V_a}{3R_a} \quad . \quad . \quad . \quad (5)$$

so that both constituent currents are known. The value of this is seen when we replace the two separate idealized valves by a single imperfect diode, having, for example, a non-uniform cathode temperature, in which some parts of the cathode reach temperature-limitation while other parts are still space-charge-limited; by means of equations (4) and (5) we can determine what proportions of the anode current of such a diode are to be attributed to each regime.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† "A Theory of Fluctuation Noise," *Journal I.E.E.*, 1938, vol. 82, p. 522.

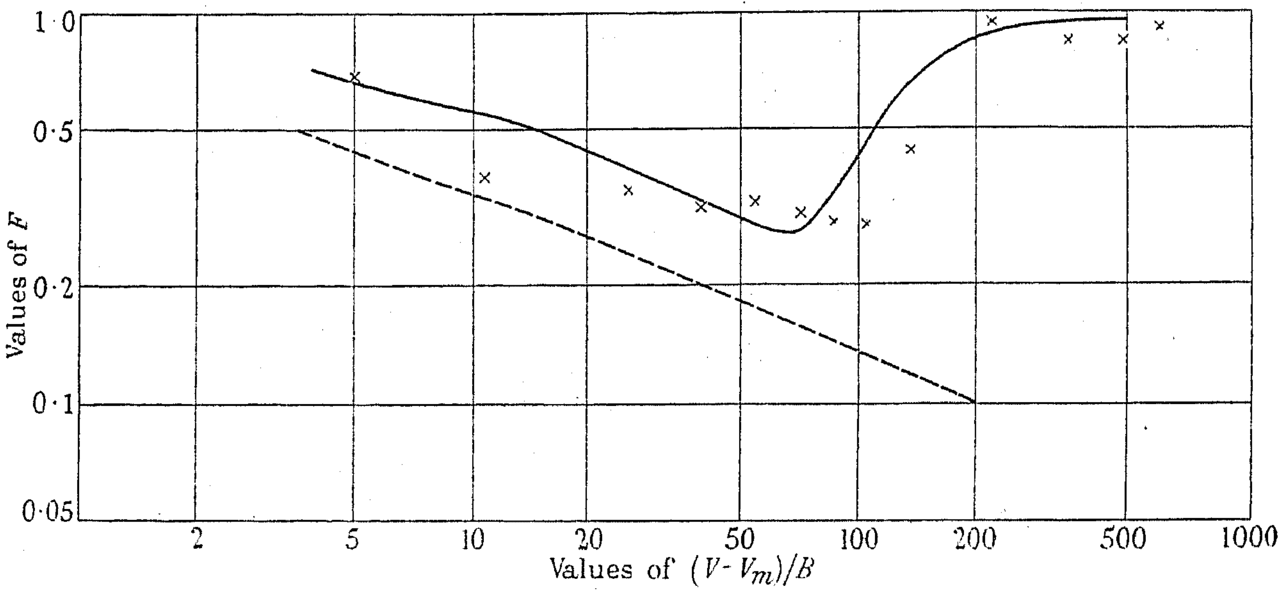

Fig. 3.—" Rauschröhre 6."

Calculated curve ————
Jacoby and Kirchgessner measured points × × ×
Schottky calculated curve of lower limit of noise - - - - - -

Before investigating the fluctuation noise to be expected from the system, we must decide what units are to be employed in specifying it. The obvious course of using absolute units is open to the objection that it does not give a ready comparison between valves of different dimensions [different values of the constant a in equation (1)]. Following the example of previous authors, therefore, the results are preferably expressed as the ratio of the observed noise to the noise that would be generated by an equal current i_0 flowing through a temperature-limited valve connected in the same measuring circuit. This ratio has sometimes been called the " smoothing factor "; but that name is undesirable since it is suggestive of the " thermal noise plus shot noise " theory, which is not consistent with the hypotheses adopted by the author. The ratio in question will therefore be termed simply " the noise ratio." It is now necessary to distinguish between two possible noise ratios. First, one may take the ratio of the mean-square values, and this is the factor which Dr. F. C. Williams denotes by A;* alternatively, one may take the ratio of the root-mean-square values, and this is the factor denoted by F in the work of Prof. W. Schottky and his colleagues.†

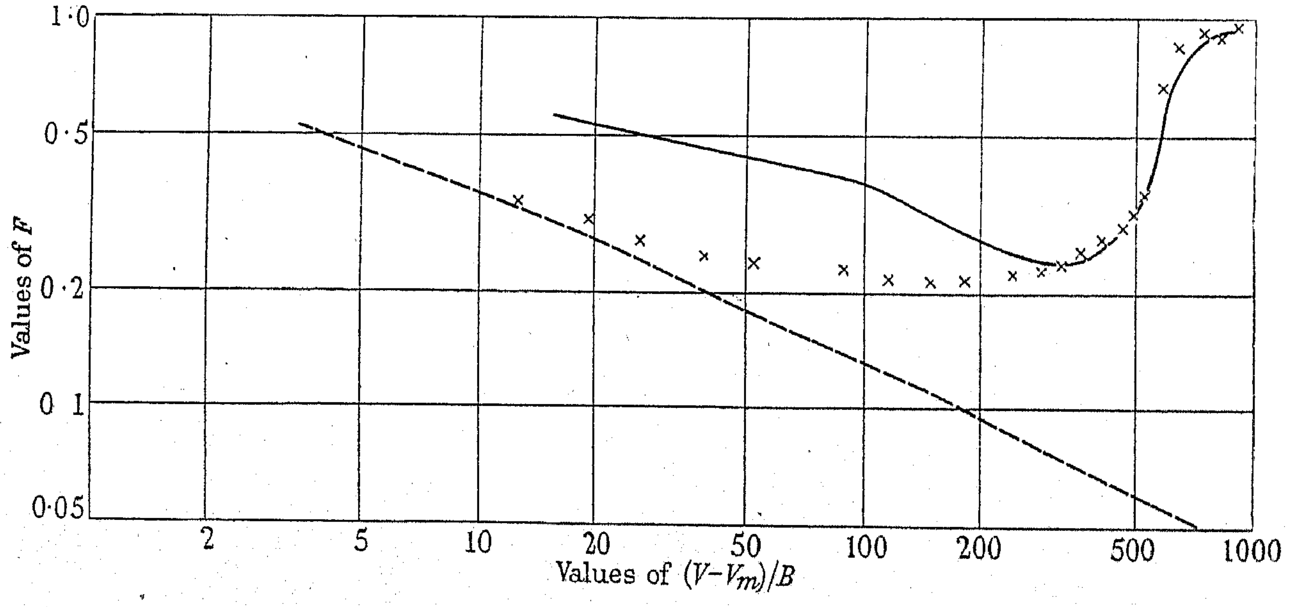

Fig. 4.—"Rauschröhre 7."
(Details as Fig. 3.)

The mean-square value is obviously the factor of greater primary significance, but the derived root-mean-square value will have practical advantages (as pointed out by Prof. Schottky) when the theory can be applied to amplifying valves instead of diodes. For the noise problem normally arises in voltage amplifiers, whose signal output is specified linearly in volts, not as a squared value, so that signal/noise ratios will be more easily calculated if r.m.s. noise values are used. In practice F is obtained when required simply by taking the square root of A.

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* See, for example, *Journal I.E.E.*, 1936, vol. 79, p. 349.

† See, for example, *Wissenschaftliche Veröffentlichungen aus den Siemens-Werken*, vol. 16, part 2.

Returning to Fig. 2, let us calculate the total fluctuation current to be expected from the two currents i_1 and i_2, which are assumed both to flow through a noise-measuring system consisting of the load circuit R, C, and an amplifier. Considering a narrow frequency band df, valve (*b*) will contribute a "shot noise" fluctuation current of mean-square value

$$\overline{I_s^2} = 2i_2e \, . \, df \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Now it was shown in the previous paper* that a valve of $\frac{3}{2}$-power law and slope resistance R_a appears as a thermal-noise source of mean-square e.m.f.

$$\overline{V^2} = 4(1\cdot 2)R_ak(T/2) \, . \, df \quad . \quad . \quad . \quad (7)$$

The mean square fluctuation *current* in such a valve must therefore be

$$\overline{I_t^2} = \frac{\overline{V^2}}{R_a^2} = \frac{4(1\cdot 2)kT}{2R_a} \cdot df \quad . \quad . \quad . \quad (8)$$

Since we are concerned with mean-square values of random currents, the total fluctuation noise is the sum of the components from valve (*a*) and valve (*b*), namely

$$\overline{I_0^2} = \left\{2i_2e + \frac{4(1\cdot 2)kT}{2R_a}\right\}df \quad . \quad . \quad . \quad (9)$$

But the noise from the whole current i_0 if it were entirely temperature-limited would be

$$\overline{I_x^2} = 2i_0e \, . \, df \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

On dividing (9) by (10), the mean-square noise ratio is

$$\frac{\overline{I_0^2}}{\overline{I_x^2}} = A = \frac{i_2}{i_0} + \frac{1\cdot 2kT}{i_0eR_a} \quad . \quad . \quad . \quad . \quad (11)$$

The factor F is then obtained as the square root of A.

This method of calculation has been applied to the two diodes described as "Rauschröhre 6" and "Rauschröhre 7" in a paper by H. Jacoby and L. Kirchgessner,† and Figs. 3 and 4 show a comparison of their published measurements of noise ratio with the values of F calculated by the method described above from their published i_a/V_a characteristics. In view of the fact that the published characteristics are printed to a size of graph of $2\frac{3}{8}'' \times 3''$ only, and as it was necessary to re-plot these and apply graphical differentiation to obtain values of R_a,‡ the agreement of theory with experiment is considered to be good. The abscissae are as in Jacoby and Kirchgessner's paper, in units of $(V - V_m)/B$, where $(V - V_m)$ is the potential difference between anode and potential minimum, and B is the equivalent in volts of the mean emission energy of the electrons ($B = kT/e$). The potential minimum has been calculated in terms of the ratio of the observed anode current at any voltage to the total cathode emission, the latter being assumed to be equal to the saturation value of anode current reached at high anode voltage.

As an indication of the values involved, a set of figures corresponding to the curve in Fig. 3 is given in the Table.

The best basis of comparison between diodes and triodes is in terms of the ratio of working anode current to total cathode emission. Let us assume that a triode amplifying valve has a working range of anode current from 10 % to 50 % of cathode emission. Then in Fig. 3 and the Table it will be seen that over this range for the diode the temperature-limited component of current i_2 contributes 60 % to 90 % of the noise, though it is only of the order of 10 % to 15 % of the anode current. This indicates at once the liability of any commercial valve to have a noise level far above that predicted by the thermal theory on the assumption of complete space-charge limitation. It also indicates the difficulty of checking the theory by published results of other workers, since very precise knowledge of the i_a/V_a characteristic is necessary to determine i_2 with the required accuracy. The d.c. characteristics of the valve have not hitherto been considered of fundamental importance to the theory of fluctuation noise, and the author has so far been unable to find published results for triodes which give suitable data.

Table

V	i	R_a	i_1	i_2	$\frac{6kT}{5eR_a}$ $\times 10^{-3}$	F
1·35	0·192	7 500	0·12	0·072	0·028	0·722
2·60	0·391	5 500	0·316	0·075	0·038	0·538
3·77	0·637	4 550	0·553	0·084	0·046	0·452
6·25	1·23	3 650	1·14	0·09	0·057	0·346
11·09	2·58	3 000	2·46	0·12	0·069	0·272
13·4	3·40	2 940	3·03	0·37	0·071	0·36
13·9	3·5	2 940	3·04	0·46	0·07	0·388
17·0	4·57	2 850	3·98	0·59	0·073	0·38
20·5	5·66	3 300	4·15	1·51	0·063	0·526
34·5	7·41	10 050	2·29	5·12	0·02	0·841
51·7	8·20	29 500	1·17	7·03	0·007	0·926
70·5	8·71	42 000	1·12	7·59	0·005	0·934
89·7	8·89	57 000	1·05	7·84	0·004	0·946

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* *Loc. cit.*

† *Wissenschaftliche Veröffentlichungen aus den Siemens-Werken*, vol. 16, part 2, p. 42.

‡ A curve of R_a against i_a is plotted in the published paper, but it was apparently obtained by measurement on a bridge; although satisfactory for the straighter parts of the characteristic, it has not the high precision required for the present purpose in the region of the upper bend. The graphical method therefore had to be used to obtain values of R_a.

REPORT OF THE COUNCIL FOR THE YEAR 1938-1939, PRESENTED AT THE ANNUAL GENERAL MEETING OF THE 11TH MAY, 1939

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REPORT

It is with pleasure that the Council present to the members, on the occasion of the Sixty-seventh Annual General Meeting, their Report for the year 1938–39, covering the period 1st April, 1938, to 31st March, 1939.

In submitting this account of The Institution's activities, the Council wish to put on record their keen appreciation of the services rendered by the many members who have assisted them, by service on Committees both at Headquarters and locally, and in other ways, in their endeavours to enhance the prestige of The Institution and to maintain its position in the forefront of electrical progress.

(1) THE SECRETARY

In the January, 1939, issue of the *Journal* it was announced that the Council had received with very much regret an intimation from Mr. P. F. Rowell that he desired to retire from the Secretaryship at the end of the present Session. The appointment of a successor is at present under consideration.

(2) MEMBERSHIP OF THE INSTITUTION

The changes in the membership since the 1st April, 1938, are shown in a Table included in Appendix A.

The following Table shows the net growth of membership for the last 10 years:—

Year	*Membership*	*Increase*
1930	14 200	639
1931	14 670	470
1932	14 884	214
1933	15 149	265
1934	15 619	470
1935	16 150	531
1936	16 788	638
1937	17 399	611
1938	18 252	853
1939	19 044	792

(3) HONORARY MEMBER

The Council have pleasure in recording that, as announced at the Ordinary Meeting on the 2nd February, 1939, they have elected Sir Archibald Page (Past-President) to be an Honorary Member of The Institution.

(4) FARADAY MEDAL

The seventeenth award of the Faraday Medal has been made by the Council to Dr. W. D. Coolidge.

(5) HONOURS AND DISTINCTIONS CONFERRED ON MEMBERS

Baron.
Stamp, Sir Josiah, G.C.B., G.B.E., D.Sc., Sc.D., LL.D. (Companion).

Knight Bachelor.
Brown, Harry Percy, C.M.G., M.B.E. (Member).
Howard, Henry George (Member).

C.B.E.
Bishop, Harold, B.Sc.(Eng.) (Member).
Milliken, Robert Cecil, Brigadier, T.D. (Member).
Wedmore, Edmund Basil (Member).

O.B.E.
Baldwin, Francis George C. (Member).
Ramsey, Arthur George, M.B.E., B.Sc.(Eng.) (Member).
Smith, Benjamin Spalding (Member).

M.B.E.
Brazier, Clifford Claude H. (Associate Member).
Knight, Edwin William (Associate Member).

(6) DEATHS

The Council regret to have to record the death of the following 129 members of The Institution during the year:—

Honorary Members

Blondel, Prof. A.
Mordey, W. M.
Snell, Sir John F. C., G.B.E.
Thury, Dr. René.

Members

Alexander, D.
Ashcroft, E. A.
Balfre, P.
Bates, Col. D., T.D., J.P., D.L.
Beetlestone, M. A.
Begg, J. B. A.
Blackman, A. S.
Blennerhassett, R. F. P.
Bright, S.
Brown, W. A.
Callender, Sir T. O., J.P.
Clarke, J. B.
Clay, Col. C. B.
Colyer, J. F. H.
Cowell, J. R.
Dawson, Sir Philip, M.P.
De Nordwall, C. F.
Denton, H. H.
Edwards, J. P.
Erskine, A.
Friedlaender, P. R.
Grace, C. B.
Harmer, A. F.
Hawkins, C. C., C.B.E., M.A.
Hefford, C. N., M.Sc.
Hetherington, E. F.
Highfield, W. E.
Hill, E. L.
Hood, T.
Insull, S.
Lanphier, R. C., Ph.B.
Loftus, J. J.
Lundberg, G. C.
Makovski, A. W.
Morton, J. A.
Parry, E.
Polyblank, Lt.-Col. W. J., O.B.E.
Preston, G. F. L., C.B.E.
Ram, G. S., O.B.E.
Ratcliff, H. A.
Robertson, Col. F. W., O.B.E., R.E.
Scott, W. H., O.B.E.
Severs, J.
Shuttleworth, C. I.
Sully, H. T.
Tabor, H. J. H.
Thomson, G. H.
Webber, Major O. T. O'K.
Weightman, R. W.
Whipp, S.
Youngs, C. J.

Associate Members

Adam, M. A.
Alabaster, Bt.-Major E. O.
Ardis, R.
Badger, W. H.
Baldwin, F. J.
Bannister, H.
Barclay, W. R., O.B.E.
Bolton, R. A. R.
Broadbent, D. R.
Burgess, A. F., B.Sc. (Eng.).
Burgis, J. S.
Carrigg, T. B.
Cook, J. W. D.
Cooke-Smith, H.
Delaney, S.
Dudgeon, H. M.
Eden-Green, S.
Gresty, G.
Heritage, H. J. E.
Higginbotham, G. E.
Jones, W.
Kerr, H.
Lea, W. H.
Lees, A.
Meek, L.
Mennie, G. A.
Merrett, Prof. W. H.
Metelerkamp, A. R.
Mitchell, P. G.
Morris, L. C.
Oman, G. R., B.Sc.Tech.
Orringe, J.
Osborne, K. L., B.Sc. (Eng.).
Packer, J. L.
Powning, W. H.
Read, F. W.
Richardson, G.
Rouse, F. R. C.
Rugeroni, J. A.
Sampson, T. W.
Saycatch, J.
Shepheard, H. B.
Shirshov, I.
Soares, F. B.
Storry, A.
Symonds, P. H.
Vaux, A.
Webb, G. F.
Welch, T.
Wynne, W. R.

Companions

Herbert, G.
Milford Haven, The Most Hon. The Marquess of, G.C.V.O.
Wilson, E.

Associates

Burton, W. F.
Holmes, W.
Keillar, A. B.
Kerr, W. F.
Thynne, A. W.

Graduates

Crosby, P. N.
Lawton, C. T.
Low, J. P., B.Sc.
Mackay, W. Y., B.Sc.
McLeod, P. H.
Millar, D. P. M.
Salinger, C. M.
Scott, T. H., B.A.
Stockwell, R. W.
Warburton-Gray, S. G. F.
Wells, E. G., B.Sc.(Eng.).

Students

Chatton, L. T.
Griffith, W. H. D.
Kenyon, R. T.
Mackenzie, N. M.
Viegas, J. F.

(7) VOLUNTARY NATIONAL SERVICE

The Government has asked for the co-operation of The Institution in connection with a Central Register which is being established by the National Service Department of the Ministry of Labour and which will consist of the names of persons of scientific, technical, professional, and higher administrative qualifications who would be prepared in war time to do appropriate paid work in their professional capacity.

As already stated in the *Journal*, the President has accepted an invitation to serve on the Advisory

Council of the Central Register which the Minister of Labour and the Lord Privy Seal have appointed. The Advisory Council, consisting of representatives of the major professional, scientific, and technical organizations and of the Service Departments, will advise the Minister in regard to the work of the Central Register.

The Advisory Council has set up Committees to deal with different branches of work, and Engineering is dealt with by the "General Engineering Committee," on which The Institution is represented by the President and Mr. H. T. Young, Past-President. This Committee has appointed Sub-Committees to deal in more detail with the different branches of engineering, and one of these deals with electrical engineering. It consists of 12 members, all present or past Members of Council, appointed on the nomination of The Institution, with the President as its Chairman. In collaboration with the National Service Department of the Ministry of Labour it has been responsible for the preparation of a registration questionnaire, which with a covering letter has now been issued to members, and it will in a national emergency advise the Ministry of Labour on the use of the electrical engineering section of the Central Register. It is also advising the Ministry of Labour on the Schedule of Reserved Occupations, so far as it applies to the electrical industry.

Members of all classes who will be prepared in war time to do appropriate work in their professional capacity, and to accept such suitable work as is offered to them, except so far as they are then already engaged on work of greater importance from the point of view of National Defence, are invited to offer their services to the Government by completing and returning to the Secretary of The Institution the above-mentioned registration questionnaires.

The Institution is advised by the Government that:

(*a*) In war time, machinery will be set up to determine priority of work from the point of view of national importance, but members should not be deterred from offering their services because they are already under an obligation for other forms of National Service or are at present engaged on work regarded as of national importance.

(*b*) The selection of persons from the Central Register will be made with the advice of the Electrical Engineering Sub-Committee, which will advise such selection only if the services of a person already engaged on work of national importance are required for a post of greater national importance. No such selection will be made without advising the person's employer, if any, and the Sub-Committee will take account of any representations which may be made to it by such employer.

(*c*) Although it is a matter for the discretion of each individual whether he should enrol in the Central Register, it is suggested that he should consult his employer, if any, or inform him of the action contemplated.

The Council of The Institution, in addition to agreeing to co-operate in establishing a National Register, has decided that it should itself prepare a record of the qualifications of all the members of The Institution so that complete data may be available, in a national emergency, for co-ordinating the electrical engineering resources of the nation. In order to enable The Institution to compile this record, an additional registration card has been sent to every member with a request for its completion and return to the Secretary, even if the member is not at present prepared to offer his services to the Government or is already employed in one or other of H.M. Forces or the Civil Service.

(8) EXAMINATIONS

Graduateship Examinations were held for a total of 606 candidates in May and November, 1938, in London, Belfast, Birmingham, Cardiff, Dublin, Glasgow, Loughborough, Manchester, and Newcastle-on-Tyne, and also, in November only, in Argentina, Australia, Ceylon, China, Federated Malay States, India, Malta, New Zealand, South Africa, and South Iran.

Examinations in English only were also held in May and November, 1938, at various centres in Great Britain for 279 holders of National Certificates in Electrical Engineering.

In addition 40 theses, submitted by candidates who were permitted by the Council to do so as an alternative to sitting for the Graduateship Examination, were examined. The Page Prize was awarded to Mr. R. Newing for his thesis entitled "Equipment and Distribution for Large Industrial Undertakings." This prize is offered annually for the best paper or thesis submitted in lieu of the Examination, provided that one has been received of sufficient merit to justify an award.

The Engineering Joint Examination Board, which was set up last Session by the Engineering Joint Council, has commenced its meetings, and progress is being made with the drawing up of a scheme and with the preparation of the syllabuses of the subjects for a Common Preliminary Examination, which will be at the disposal of those constituent Institutions of the Joint Council who desire to adopt it as a qualification for membership.

(9) NATIONAL CERTIFICATES AND DIPLOMAS IN ELECTRICAL ENGINEERING

England and Wales.—In 1938 the Joint Committee, representing the Board of Education and The Institution, were associated with the final examinations of 226 courses at colleges and schools in England and Wales, approved in connection with the above certificates and diplomas.

The final examinations were held during the summer, and the number of awards was as follows:—

Ordinary Certificates	917
Higher Certificates	379
Higher Certificates endorsed ..	85
Ordinary Diplomas	33
Higher Diplomas	9
Total	1 423

Scotland.—In conjunction with the Scottish Education Department, The Institution was associated with 15 courses in Scotland during the year under review.

The final examinations were held during the summer, and the number of awards was as follows:—

Ordinary Certificates	35
Higher Certificates	15
Higher Certificates endorsed ..	3
Higher Diplomas	8
	61

(10) SCHOLARSHIPS

The following Scholarships have been awarded by the Council during the Session:—

Ferranti Scholarship

(Annual Value £250; tenable for 2 years.)
L. S. Piggott, M.Sc.(Eng.) (Oxford University).

Duddell Scholarship

(Annual Value £150; tenable for 3 years.)
J. B. J. Higham (Penarth County School).

Silvanus Thompson Scholarship

(Annual Value £100, plus tuition fees; tenable for 2 years).
H. Darnell (Mersey Railway Company).

William Beedie Esson Scholarship

(Annual Value £120; tenable for 2 years, renewable in approved cases for a third year.)
No award.

Swan Memorial Scholarship

(Value £120; tenable for 1 year.)
J. G. Hutton, B.Sc. (Sunderland Technical College).

David Hughes Scholarship

(Value £100; tenable for 1 year.)
H. E. Newton (Sheffield University).

Salomons Scholarship

(Value £100; tenable for 1 year.)
C. Halliday (King's College, Newcastle-on-Tyne).

Paul Scholarship

(Annual Value £50; tenable for 2 years.)
No award.

Thorrowgood Scholarships

(Annual Value £12 10s. each; tenable for 2 years.)
E. C. Norris (Southern Railway Company).
C. R. Smith (London and North-Eastern Railway).

War Thanksgiving Education and Research Fund (*No.* 1).

Grant of £50 to:
J. W. Carroll (King's College, London).
Grants of £25 each to:
E. Franklin (Birmingham University).
G. Y. Shute (University College, Nottingham).

All the scholarships and grants mentioned above may be awarded annually, with the exception of the Paul and William Beedie Esson Scholarships, which are awarded in alternate years only. When an award of the latter scholarship is renewed for a third year, however, the next award is deferred for a year.

(11) INSTITUTION BUILDING

As in past years, the use of The Institution's premises has been granted without charge to a number of kindred societies in connection with their meetings, and 163 such meetings have been held during the past year.

(12) UNAUTHORIZED USE OF MEMBERSHIP INITIALS

There have been several cases during the past year of the use, by unauthorized persons, of initials or descriptions implying that they were members of The Institution. It has been possible in each case to ensure the discontinuance of the practice by the person concerned without the necessity of taking legal action.

(13) MEETINGS

During the past 12 months, 555 meetings have been held in London and at the Local Centres by the members, the Council, and the various Committees. A detailed statement is given in Appendix B.

The average attendance at the 17 Ordinary Meetings held in London was 251, compared with 255 for last Session.

On the occasion of the reading of the paper on " Empire Telegraph Communications " by Mr. K. L. Wood on the 15th December, 1938, an interesting demonstration was given by the author, communication being established, in the Lecture Theatre, with Cape Town on a wireless automatic printing circuit. This was followed by a demonstration of printing on a cable circuit established between The Institution and Singapore and back. In the course of these demonstrations messages of greeting were received in turn from The Institution's Local Honorary Secretary for the Cape, Natal, and Rhodesia, the Chairman and members of the I.E.E. Ceylon Committee, and the President and members of the Engineering Association of Malaya, to all of whom suitable replies of appreciation from the President were despatched over the same apparatus, conveying reciprocal greetings from The Institution.

The programme this Session included a Discussion on " Non-destructive Testing," arranged by the Joint Committee on Materials and their Testing, which was, at the invitation of the Joint Committee, held under the auspices of The Institution, the President (Dr. A. P. M. Fleming) being in the chair, supported by Dr. H. J. Gough, the Chairman of the Joint Committee. Seven introductory papers on the subjects of Magnetic and Electrical Methods, X- and Gamma-Rays, and Acoustical and General Methods, which had been prepared by authors representing Great Britain, the Continent of Europe, and the United States of America, were presented at this meeting, the attendance at which consisted largely of members of the various technical institutions and societies represented on the Joint Committee.

The Institution co-operated with some 18 other bodies in the holding in March, 1939, of a " Joint Meeting of Kindred Societies," arranged by The Institution of Automobile Engineers, for the discussion of papers on the subject of " Comfort in Travel."

(14) PREMIUMS

The Premiums awarded by the Council for papers read at meetings or accepted for the *Journal* will be announced about the time of the Annual General Meeting.*

(15) LOCAL CENTRES AND SUB-CENTRES

The attendances and proceedings of the Local Centres and Sub-Centres, full details of which are contained in the Annual Reports presented to the local members, continue to maintain their high standard. It is fully recognized by the Council that these branches of The Institution represent a most important part of its constitution, and it is desired to record warm appreciation of the valuable work carried on by the officers and committees of the Local Centres and Sub-Centres, which contributes so largely to the continued progress of The Institution.

The President attended functions at the Centres at Birmingham, Dublin, Glasgow, Leeds, Liverpool, and Newcastle-on-Tyne, as well as at the Devon and Cornwall, East Midland, Northern Ireland, Sheffield, and Tees-Side Sub-Centres. He was represented at the Annual Dinner of the North-Western Centre and at the Conversazione of the Hampshire Sub-Centre by Mr. J. M. Kennedy, Past-President, and at the Annual Dinner of the Western Centre by Mr. J. R. Beard, M.Sc., Vice-President.

In addition to the above, the four Vice-Presidents—Sir Noel Ashbridge, Mr. J. R. Beard, Professor C. L. Fortescue, and Mr. Johnstone Wright—have among them, at the invitation of the Local Committees and in accordance with the scheme first put into operation last year, attended various meetings of the Local Centres during the Session. These visits are regarded by the Council as a helpful factor in maintaining the essential contact between the local Committees and Headquarters, which is already secured, in part, by the attendance of the Centre Chairmen at meetings in London of the Council and its Committees.

Members are reminded that local technical library facilities are available at Birmingham, Dublin, Dundee, Liverpool, Edinburgh, Glasgow, Leeds, Loughborough, Manchester, Middlesbrough, Newcastle-on-Tyne, Portsmouth, and Southampton. Full details of the arrangements for borrowing or referring to the books in these libraries can be obtained on application to the Local Honorary Secretaries.

The Annual Meeting of the Honorary Secretaries of Local Centres and Sub-Centres was held in London on the 9th February, 1939, when matters of common interest in regard to local organization and administration were discussed.

(16) LOCAL HONORARY SECRETARIES ABROAD

The Council have received with regret a communication from Dr. F. A. Gaby, The Institution's Local Honorary Secretary for Canada, tendering his resignation from that office because he is no longer connected with the electrical industry. The cordial thanks of The Institution have been conveyed to Dr. Gaby for the services rendered by him during his term of office.

The appointment of a successor is under consideration.

(17) METER AND INSTRUMENT SECTION

The membership of the Meter and Instrument Section is now 726. Eight meetings of the Section have been held during the past year, the average attendance being 114, which compares with 113 during the preceding 12 months. The meetings included one devoted to an informal discussion. Demonstrations of apparatus accompanied papers whenever practicable, and added greatly to the interest and success of the meetings.

The Committee wish to remind the members that short demonstrations will be welcomed of apparatus and processes which come within the scope of the Section. These need not necessarily relate to the subject matter of the paper being read on the same evening.

The Summer Visit for 1938 was held in Manchester and district on Saturday, 7th May, and about 100 members and ladies took part. In the morning, visits were paid to Prestwich step-down transformer substation and a typical network substation of the Salford Corporation, the Barton power station of the Manchester Corporation, the cotton mills of Messrs. Tootal Broadhurst Lee Co., Ltd., at Newton Heath, the showroom of the Calico Printers' Association, Ltd., and Chetham's Blue Coat School, Hospital, and Library. After lunch at Barton power station as the guests of the Manchester Corporation Committee, the party proceeded to Chester, where the Castle was visited, followed by a drive through the old part of the city to the cathedral, tea being provided by the General Electric Co., Ltd., in the refectory. The Section Committee wish to record their thanks for the hospitality accorded by all those concerned.

(18) TRANSMISSION SECTION

The Transmission Section now has a membership of 1 683. Seven meetings have been held during the past year, the average attendance being 98, compared with 117 during the preceding 12 months. The papers have been of a high standard and have been followed by excellent discussions.

A week-end visit was paid to Belgium from the 13th to the 17th May, 1938, 48 members taking part. The Union des Exploitations Électriques en Belgique, in conjunction with the Association des Centrales Électriques Industrielles de Belgique, very kindly made the necessary arrangements in Belgium. The programme included visits to the control room, the telephone and remote measurement installations, and the high-frequency remote metering between the Liége and Aubange substations (150-kV line from Liége to Luxembourg) and the relay room of the Société Anonyme Union des Centrales Électriques Linalux at Liége, the works of the Société Belge de l'Azote at Ougrée, the Centre d'Étude de l'Action du Vent sur les Pylônes at Zeebrugge, the Schelle power station of the Société d'Électricité de l'Escaut, and the Zeebrugge War Museum.

The Summer Visit of the Section was held in North Wales on Saturday, 24th, and Sunday, 25th September, 1938, when nearly 90 members and ladies were the guests of the North Wales Power Co., Ltd., and the J. L. Eve Construction Co., Ltd. The former company's hydro-electric power stations at Maentwrog and Dolgarrog were visited and many of their transmission lines were seen. Visits were also paid to the Penrhyn slate quarries, Bethesda, and the Penmon transmitting station of the British Broadcasting Corporation.

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* See page 768.

Continuing the series of visits to works, etc., inaugurated three years ago, an interesting visit was paid to the Research Laboratories of the British Electrical and Allied Industries Research Association, at Perivale, Middlesex. Three parties inspected the Laboratories on Tuesday, 29th November, Wednesday, 30th November, and Wednesday, 7th December, 1938. In all about 100 members took part.

The thanks of the Section are due to all those mentioned above for the excellent arrangements made and the hospitality accorded throughout the Visits referred to.

The Annual Conversazione and Dance of the Section, held on Wednesday, 2nd November, 1938, was attended by 218 members and guests.

(19) WIRELESS SECTION

The membership of the Wireless Section is now 1 079. Seven meetings have been held during the past year, at which 10 papers were read, and two lectures delivered. These were by Dr. Ralph Bown on " Researches in Radio Telephony " and Sir Noel Ashbridge, B.Sc.(Eng.) on " Broadcasting and Television." In addition, eight papers have been published or accepted for publication in the *Journal*. The average attendance at the meetings was 195, compared with 131 for last Session.

Three Informal Meetings of the Section have been held, and the average attendance was 130.

The Summer Visit for 1938 took place on Saturday, 28th May, 1938, when a party consisting of 65 members visited the Research Laboratories of the General Electric Co., Ltd., and the Osram-G.E.C. Lamp and Glass Works, Wembley. Thanks have been accorded to the company for the arrangements made to receive the party.

(20) SUGGESTED NEW SECTIONS

A suggestion has been received from a member that an Education Section of The Institution should be set up to include in its scope all matters relating to the education of the whole of the personnel for the electrical engineering industry.

The Council have given this suggestion careful consideration, but feel that the subject of education does not lend itself to treatment by one special Section, and that there is room within the existing Sections and Ordinary Meetings for the subject to be dealt with adequately. To ensure, however, that there should become available in future a supply of papers suitable for presentation at Ordinary Meetings and meetings of the various Sections, an " Education and Training Technical Committee " is to be set up and will function on lines similar to the Technical Committees already in existence, whose duty it is to secure an adequate supply of papers on their respective subjects, for reading at meetings or for publication in the *Journal* without being read.

The Council are also giving consideration to a further suggestion that an Installation Section should be set up.

(21) INFORMAL MEETINGS

Eleven meetings have been held during the year, the average attendance being 65, the same as last year.

In addition, three joint Informal Meetings have been held in conjunction with The Institution of Civil Engineers and The Institution of Mechanical Engineers. The meetings were held at each Institution in turn, and the attendance on the occasion of the meeting held in the Lecture Theatre of The Institution numbered 200, of whom 124 were members.

The Informal Meetings Committee again cordially invite members to write to the Secretary indicating subjects which they wish to suggest for discussion. Offers from members to open discussions will also be welcomed and carefully considered by the Committee.

The Council wish to remind the younger members, and particularly those who have not yet attended any of the meetings, that these are arranged primarily for them, with the object of their gaining experience in public speaking and thereby acquiring confidence to take part in the discussions on papers at the Ordinary Meetings.

The proceedings of the Informal Meetings are not reported by the Press, and only a précis of the discussions (prepared by a member of the Committee) is sent to the technical journals for publication.

(22) STUDENTS' SECTIONS

Full programmes of meetings, visits to works, and social functions, details of which have been given from time to time in the *Students' Quarterly Journal*, have been carried out during the Session by the nine Students' Sections at London, Birmingham, Bristol, Glasgow, Leeds, Liverpool, Manchester, Newcastle-on-Tyne, and Sheffield.

The membership of the nine Sections is in the aggregate 4 365, which includes 2 004 Graduates up to the age of 28, who are entitled under the Bye-laws to the same privileges as Students.

The " Students' Lectures " were delivered this Session by Mr. J. W. Beauchamp and Mr. A. Duxbury, who on this occasion visited the places indicated:—

Lecturer.	*Subject.*	*Place.*
Mr. J. W. Beauchamp	" The Electrical Industry as an Economic and Social Force "	London Birmingham Bristol Liverpool Manchester
Mr. A. Duxbury	" Public Speaking "	Edinburgh Glasgow Leeds Newcastle-on-Tyne Sheffield

The total attendances at the 10 lectures were approximately 471, compared with 490 for the 10 lectures given last Session. Further lectures will be delivered next Session, and arrangements for these are now being made.

The Eighth Annual Meeting of the Honorary Secretaries of the Sections was held in London on the 10th February, 1939, when a useful discussion took place on points of common interest.

The *Students' Quarterly Journal*, now completing its ninth volume, has again been effective in maintaining a lively co-operation between the various Sections. In particular, the Students' Calendar has been revived so that members who live within reach of more than one Section, or who are travelling round the country, may have details of the meetings in Sections other than their own.

An increased number of publishers have availed themselves of the facilities for the review of new technical books, and in the June 1938 issue an index was included of all books reviewed in the past three volumes, supplementing the index published in vol. 6, 1935, which dealt with all the books reviewed up to that time. These book reviews have proved of great assistance to the Section members.

Students and Graduates who have transferred to Corporate Membership may continue to receive the *Students' Quarterly Journal* on payment of an annual subscription of 6s., the price to the general public being 10s. per annum. On forwarding a remittance of 1s. 6d. to the Secretary of The Institution any senior member may obtain a specimen copy.

In August last a Summer Meeting to Berlin, Essen, Eindhoven, and Brussels was organized by the London Students' Section (in conjunction with the National Union of Students). The party, which numbered 65 and included members from nearly every Students' Section, had a most successful tour, a full account of which was published in the September 1938 number of the Students' Journal.

The London Students' Section this year failed to regain the " Young " Trophy in the Sports Contest between that Section and the Students and Graduates of The Institutions of Civil and Mechanical Engineers. The Section held the Trophy for the first three years of the Contest (1934–36), but in 1937 it was won by The Institution of Civil Engineers and last Summer by The Institution of Mechanical Engineers. The Contest in 1938 again consisted of cricket, tennis, and shooting matches, and a full account was given in the September 1938 number of the Students' Journal.

(23) ACTIVITIES OF OVERSEAS MEMBERS

The Overseas Activities Committee of the Council are very gratified at the continued progress of The Institution overseas. Details have been received of meetings at which papers have been read and discussed, and of other functions arranged by the Argentine and China Local Centres and by the Overseas Committees in Queensland, South Australia, Ceylon, Bombay, Calcutta, and Madras.

In some instances papers already read in London have been read and discussed, and papers have also been written and presented by local members.

The schemes of co-operation with other Institutions in Argentina and China continue to operate satisfactorily.

The seventh Annual Conversazione and Reunion of members from overseas and their ladies was held in The Institution building on Thursday, 16th June, 1938. The total attendance was about 130, and the arrangements were similar to those made for the functions held in previous years. An account of the proceedings was published in the *Journal* for September, 1938 (vol. 83, page 436).

(24) CO-OPERATION BETWEEN ENGINEERING INSTITUTIONS

The Council continue to bear in mind the possibility of advancing co-operation with other engineering Institutions.

As mentioned in the last Annual Report a special Committee was set up by the Engineering Joint Council to consider what steps could be taken further to bring together the overseas members of the various engineering Institutions, the suggestion being that the schemes of co-operation already in existence in China and Argentina might be the basis of similar co-operation elsewhere overseas.

The report of the special Committee has now been considered by the Councils of this and the other Institutions. As a result a Joint Committee, known as the Joint Committee on Engineering Co-operation Overseas, on which the eight constituent Institutions of the Engineering Joint Council are represented, has now been set up to consider the possibility of fostering co-operation between overseas members of these Institutions and, where there is a local Engineering Institution in existence, between those members and that Institution, and to promote such co-operation in those countries where it is found to be practicable. The Joint Committee is now actively engaged in this work.

(25) CHINESE ELECTRICAL ENGINEERING APPRENTICES AND STUDENTS

It was recorded in the last Annual Report that the Council had decided that facilities to attend Institution meetings and to use the Reference Library should, as a gesture of goodwill, be offered to Chinese electrical engineering apprentices and students who, under arrangements made by the Federation of British Industries, had been given opportunities for gaining engineering experience in Great Britain. The arrangement has continued in operation this Session, and some 18 young men, whose names have been supplied by the Federation, come within the scope of the scheme at the present time. Such of them as are engaged in the provinces have, with the ready co-operation of the Local Centres and Sub-Centres concerned, been granted privileges as regards attendance at local meetings and the use of such library facilities as may be available.

(26) REVIEWS OF PROGRESS

Continuing the series of reviews of progress in electrical engineering which have appeared in the *Journal* each year since 1926, reviews on the following subjects have been, or will be, published during 1939:—

Broadcasting and Television.
Power Stations and their Equipment.
Radio-telegraphy and Radio-telephony.
Telegraphy and Telephony.
Electricity Supply Tariffs.

Arrangements have been made for reviews on the following subjects in 1940:—

Electrical Plant and Machinery.
Electricity applied to Ships.
Electro-physics (including the Photo-electric Cell).
Electrical Illumination.
Factory Applications.

(27) FARADAY LECTURE

The Faraday Lecture this Session has been delivered by Capt. B. S. Cohen, O.B.E., who chose as his subject "The Long Distance Telephone Call—A Triumph of Engineering and Co-operation." It has been given at Belfast, Birmingham, Bristol, Dublin, Glasgow, Liverpool, Manchester, Newcastle-on-Tyne, and Southampton, and will also be given in Dundee and London before the Session closes.

The nine Lectures so far delivered this Session have been attended by audiences totalling approximately 5 840, of whom over 4 960 were non-members.

(28) SUMMER MEETING

In response to an invitation from the Committee of the South Midland Centre a Summer Meeting was held at Birmingham from the 4th to the 8th July, when some 350 members and ladies took part.

The programme commenced with an Informal Reunion, which was followed during the succeeding days by visits to the Hams Hall power station of the Birmingham Corporation, the Witton works of the General Electric Co., Ltd., the Rugby works of the British Thomson-Houston Co., Ltd., the Longbridge works of the Austin Motor Co., Ltd., the Stourport power station of the Shropshire, Worcestershire, and Staffordshire Electric Power Co., and Telephone House, Birmingham. There was an evening reception by the Lord Mayor and the Lady Mayoress of Birmingham, and a dance and cabaret with the General Electric Co., Ltd., as hosts.

The programme also included excursions, on one of which the party were the guests of the Midland Counties Electric Supply Co., Ltd., and a visit to an evening performance at the Shakespeare Memorial Theatre, Stratford-on-Avon, and ended on the evening of the 8th July with a gala night at the Botanical Gardens at the invitation of the City of Birmingham Electric Supply Committee.

The thanks of The Institution have been conveyed to all those mentioned above and the Council wish to place on record their appreciation of the generous hospitality received. They also record their high appreciation of the work of the Committee of the South Midland Centre, and in particular of the Chairman of the Centre (Mr. H. Hooper) and the Hon. Secretary (Mr. R. H. Rawll).

Arrangements are being made for the Summer Meeting for 1939 to be held in Manchester and district from the 19th to the 23rd June by kind invitation of the Chairman and Committee of the North-Western Centre. Particulars have already been issued to members.

(29) ANNUAL CONVERSAZIONE

The Annual Conversazione was held on the 30th June, 1938, at the Natural History Museum, London. The total attendance of members and guests was 2 172.

(30) ANNUAL DINNER

The Annual Dinner was held at Grosvenor House, Park Lane, London, on the 9th February, 1939, when 1 152 members and guests were present. An account will be published in the *Journal*.*

(31) ANNIVERSARY CELEBRATIONS AND CONFERENCES

During the year under review, The Institution has been represented at the following Anniversary Celebrations and Conferences, etc.:—

Name of Body	*Nature and Date of Function*	*Name of I.E.E. Representative*
Association of Teachers in Technical Institutions	Annual Conference, Leeds (4–7 June, 1938)	J. G. Craven
Fifth International Congress for Applied Mechanics	Congress, Cambridge, Mass. (12–16 September, 1938)	Gano Dunn (Local Hon. Secretary for U.S.A.) Dr. A. P. M. Fleming, C.B.E., M.Sc. (then Vice-President) Dr. D. C. Jackson Dr. F. B. Jewett
Institution of the Rubber Industry	Rubber Technology Conference (23–25 May, 1938)	Dr. P. Dunsheath, O.B.E., M.A.
International Electrotechnical Commission	Plenary Meeting, Torquay (22–30 June, 1938)	Sir George Lee, O.B.E., M.C. (then President) Ll. B. Atkinson Lt.-Col. K. Edgcumbe, T.D. Roger T. Smith H. Cobden Turner
International Engineering Congress	Congress, Glasgow (21–24 June, 1938)	J. R. Beard, M.Sc. (Vice-President) Major H. Bell, O.B.E., T.D. J. Miller R. B. Mitchell
National Smoke Abatement Society	Tenth Annual Conference, Cardiff (29 September–1 October, 1938)	H. G. Weaver
Naamlooze Vennootschap tot Keuring van Electrotechnische Materialen	Inauguration of New Laboratories, Arnhem (14 October, 1938)	P. V. Hunter, C.B.E.
Royal Sanitary Institute	Annual Health Congress, Portsmouth (11–16 July, 1938)	B. Handley
Seventh International Management Congress	Congress, Washington (19–23 September, 1938)	E. S. Byng

(32) LIBRARY

During the year 668 books and pamphlets have been presented to the Reference Library by members and others, and 107 volumes were purchased. The total number of readers for the year was 7 233, of whom 1 013 were non-members, as against 7 226 and 889 respectively in 1937–38.

Ninety-three new volumes have been added to the Lending Library and 2 910 books were issued to 1 196 borrowers, the corresponding numbers for the previous year being 2 905 and 1 231 respectively.

(33) GIFTS TO THE INSTITUTION

The Council express their cordial thanks to the donors of the following gifts to The Institution:—

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* See page 745.

Donor.	*Gift.*
The Kent County Council	A Kelvin multicellular voltmeter, No. 281. A Kelvin recording voltmeter, No. 7. A Cunynghame magnetic cut-out.
Mr. J. Eck	Concentric pattern wall-socket containing fuse, with plug. A Winter 15-ampere wall-socket with earth-wire safety locking device.
Sir Harry F. Batterbee, K.C.M.G., K.C.V.O.	An early electrical influence machine.

(34) HISTORY OF THE INSTITUTION

The preparation of the "History of The Institution" by Mr. Rollo Appleyard has now been completed and the production of the book is approaching its final stages. It is hoped to effect publication at an early date.

(35) VISITING MEMBERS

Members are reminded of the reciprocal arrangements with some kindred institutions overseas for the extension of privileges to visiting members.

The bodies concerned are:

The American Institute of Electrical Engineers, New York;
The Institute of Electrical Engineers of Japan, Tokio;
The Norsk Elektroteknisk Forening, Oslo;
The Société Française des Èlectriciens, Paris;
The South African Institute of Electrical Engineers, Johannesburg; and
The Verband Deutscher Elektrotechniker, Berlin.

Formal letters of introduction to any of these may be obtained from the Secretary of The Institution.

(36) INTERNATIONAL ENGINEERING CONGRESS, GLASGOW, 1938

The Institution, in collaboration with other engineering Institutions, accorded its support to the International Engineering Congress held in Glasgow from the 21st to the 24th June, 1938, during the period of the Empire Exhibition. The programme included technical sessions, visits to works, excursions, and social events, arranged by the organizing committee. The *Transactions* of the Congress, which have since been published, contain the text of all the Addresses delivered thereat, a complete list of those who attended, and notes on the works visited.

(37) NEW ZEALAND CENTENNIAL ENGINEERING CONGRESS, 1940

The Institution received in December last a cordial invitation from the Executive Committee to appoint a delegate to attend the above Congress, which is to be held in Wellington in February, 1940, and which will form part of the celebrations of the Centenary of the official founding of New Zealand. The Council have appointed the President, Dr. A. P. M. Fleming, to represent them on this occasion, and he, in response to a suggestion from the Executive Committee that The Institution might arrange for a paper (or papers) to be presented at the Congress, has agreed to prepare a paper for this purpose.

(38) THE JOURNAL OF THE INSTITUTION

The total number of pages comprised in the two volumes of the *Journal* for 1938 was 1 624 (excluding Plates), as compared with 1 530 pages in the two 1937 volumes. In addition, publication of a certain amount of matter from the previous Session had to be held over to the 1939 volumes.

(39) REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF BUILDINGS

The Council hope shortly to approve the Wiring Regulations Committee's revision of the Regulations, so that copies of the new Edition (Eleventh) should be available in the early summer.

(40) REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF SHIPS

The Ship Electrical Equipment Committee have nearly completed the revision of the Second Edition of the Regulations, and it is hoped that the new Edition (Third) will be published during the present year.

(41) EARTHING TO WATER MAINS

The Regulations in connection with earthing to water pipes and mains, drawn up jointly by The Institution of Civil Engineers, The Institution of Electrical Engineers, The Institution of Water Engineers, the British Waterworks Association, and the Water Companies' Association, were published last autumn by The Institution of Civil Engineers. Copies can be obtained from William Clowes and Sons, Ltd., 94, Jermyn Street, London, S.W.1, price 6d. each, post free.

(42) MODEL GENERAL CONDITIONS FOR CONTRACTS

A new edition of the Model Form of General Conditions A (Revised 1938), covering the main conditions for home contracts for the supply of plant and materials and the execution of work connected therewith, has been approved by the Council for publication, and copies are available.

There is now in progress the revision of the Conditions C for the sale of goods other than cables at home without erection, which were issued in April, 1924.

(43) OPERATING THEATRES ELECTRICAL APPARATUS COMMITTEE

This Committee (referred to in the last Annual Report) has now been set up, with the concurrence of the Ministry of Health, to consider the question of electrical safety as regards the equipment of operating theatres and adjacent rooms. The Committee, which has commenced its sittings, includes representatives of the various medical bodies, the manufacturers of electromedical apparatus, and the Wiring Regulations Committee, and it will co-operate with the British Standards Institution on matters within the scope of that body.

The detail work of the Committee has been entrusted to two Sub-Committees, dealing respectively with

(i) equipment and installation, and (ii) static electrification.

(44) ENGINEERING PUBLIC RELATIONS COMMITTEE

The Engineering Public Relations Committee, the formation of which in 1937 was recorded in the last Annual Report, and upon which The Institution is represented, has continued its activities, which include the provision of lectures for schools and for the public, co-operation with the Press and with the B.B.C., the arrangement of displays at exhibitions, etc. The second of the Christmas Lectures for young people was, by permission of the Council, given in the I.E.E. Lecture Theatre on the 6th January, 1939, when a Lecture on " Speed on Land and Sea and in the Air " was delivered by Captain J. S. Irving, Captain George Eyston being in the chair. The attendance was approximately 450.

A lecture of a similar type, on " Ships and their Engines " by Engineer-Captain Edgar C. Smith, has been delivered at Edinburgh and Aberdeen.

(45) ENGINEERS' GERMAN CIRCLE

The Council agreed in 1938 to support the Engineers' German Circle, which, since its inauguration in 1931, has had the support of The Institution of Mechanical Engineers; and Mr. C. W. Marshall, who is also a member of the Circle, has been nominated by The Institution to maintain the necessary official contact with the Circle. The Institution has throughout the Session included in " Institution Notes " in the *Journal* particulars of the meetings of the Circle, so that those interested might attend. One of the Circle's meetings of special electrical interest was held in The Institution's Lecture Theatre. The meetings generally consist of a lecture in German by an eminent German-speaking engineer, followed by a short discussion in German.

(46) " SCIENCE ABSTRACTS "

The Physics volume of *Science Abstracts* for 1938 contains 5 081 abstracts, compared with 5 494 in 1937. The Electrical Engineering volume contains 3 622 abstracts, compared with 3 252.

A feature of the Annual Index to Section " A " (Physics) which has proved of considerable value since its introduction in 1934 is the " Supplementary Index of Apparatus and Instruments," in which the papers are classified under the names of the instruments and arranged in alphabetical order.

Science Abstracts, which appears monthly in two sections, namely Section " A " (Physics) and Section " B " (Electrical Engineering), consists of full abstracts from the leading scientific and technical journals and the proceedings of learned societies of the whole world, and presents in a form convenient for immediate reference a complete and concise record of the progress of physical science and electrical engineering. 1 424 members of The Institution subscribe to *Science Abstracts*, 836 to both Sections, 4 to Section " A " only, and 584 to Section " B " only, but the Council hope that in view of its exceptional value more members will become subscribers to the publication. It may be obtained, if ordered in advance, by Students of The Institution, as well as by Graduates up to the age of 28, at the special rate of 7s. 6d. per annum for both Sections, or 5s. for either the Physics or the Electrical Engineering Section, and by all other members of The Institution at 20s. for both Sections, or 12s. 6d. for either Section alone, the rates charged to the general public being £1 15s. per Section, or £3 for both Sections.

(47) BENEVOLENT FUND

The donations and subscriptions to the Fund in 1938 amounted to £4 066 7s. 1d., in which amount are included the proceeds of Golf Competitions organized by the Mersey and North Wales (Liverpool) Centre (£106 15s.), the North-Western Centre (£106), the North Midland Centre (£40 18s. 11d.), the Scottish Centre (£5 15s.), and the Incorporated Municipal Electrical Association (£12). In addition to the foregoing, the Fund benefited by the surplus of £201 11s. 6d. on the London Electrical Engineers' Ball in 1938, and £100 from the Summer Meeting at the South Midland Centre. Gifts were received from the organizers of similar functions in the provinces (£25 from the North Midland Electrical Engineers' Ball, £21 from the Sheffield Sub-Centre and Kindred Societies' Dance Fund, and £15 15s. from the North-Western Centre Manchester Engineers' Dance Committee). A special donation of £500 was received from Mr. R. W. Paul, and one of £151 14s. 5d. from Mr. H. Marryat. A legacy of £100 was also received from the estate of the late Mr. William Guy-Pell.

In the course of 1938, grants were made to 73 persons, amounting to a total of £3 826 5s. 6d. In assisting these cases, the Fund also provided for the necessities of 64 dependants.

During 1937 the amount expended in grants exceeded the income of the Fund from all sources, including dividends, by over £100. With a view to improving the financial position of the Fund the President, Dr. A. P. M. Fleming, accordingly made a special appeal to members to contribute in larger numbers, and it is gratifying to note from the Accounts of the Fund for 1938 that the financial position was greatly improved, the surplus of income over expenditure at the end of that year being £1 560 3s. 10d. The Council earnestly hope that all members of The Institution will continue to give the Fund their active support.

The Fund is able, under the provisions of the Finance Act 1922, to recover income tax on annual subscriptions, provided that the subscribing member signs a deed of covenant to give a fixed amount per annum for a minimum period of seven years. A number of contributors have agreed to subscribe under this arrangement, and if any other members wish to do so the Honorary Secretary of the Fund will be pleased to supply the necessary forms and particulars.

The Committee wish to express great appreciation to the Local Honorary Treasurers for their efforts in stimulating an active interest in the Fund among the members in the Local Centres, and their valuable assistance in the investigation of applications.

Electrical Engineers' Ball, 1939. The Ball, which was held at Grosvenor House, Park Lane, on Friday the 10th February, was again most successful, and the Fund benefited by receiving the whole of the surplus of £240 19s. 2d. Cordial thanks are due to the General and Executive Committees of the Ball and the stewards for their valuable assistance.

(48) THE INSTITUTION AND BODIES ON WHICH IT IS REPRESENTED

Appendix C (page 737) shows in diagrammatic form the organization of The Institution and the bodies on which it is represented.

APPENDIX A

Membership of The Institution

The changes in the membership since the 1st April, 1938, are shown in the following table:—

	Hon. Mem.	Mem.	Assoc. Mem.	Com.	Assoc.	Grad.	Stud.	Total
Totals at 1 April, 1938	15	2 070	7 025	106	1 366	4 586	3 084	18 252
Additions during the year:—								
Elected ..	1	2	152	5	87	279	1 042	1 568
Reinstated	—	2	6	—	3	5	8	24
Transferred to ..	—	100	388	—	3	417	—	908
Totals..	1	104	546	5	93	701	1 050	2 500
Deductions during the year:—								
Deceased ..	4	50	51	3	5	11	5	129
Resigned ..	—	7	41	5	14	69	78	214
Lapsed ..	—	11	35	1	24	83	303	457
Transferred from ..	—	—	100	—	42	344	422	908
Totals ..	4	68	227	9	85	507	808	1 708
Net Increase ..								792
Totals at 1 April, 1939	12	2 106	7 344	102	1 374	4 780	3 326	19 044

APPENDIX B

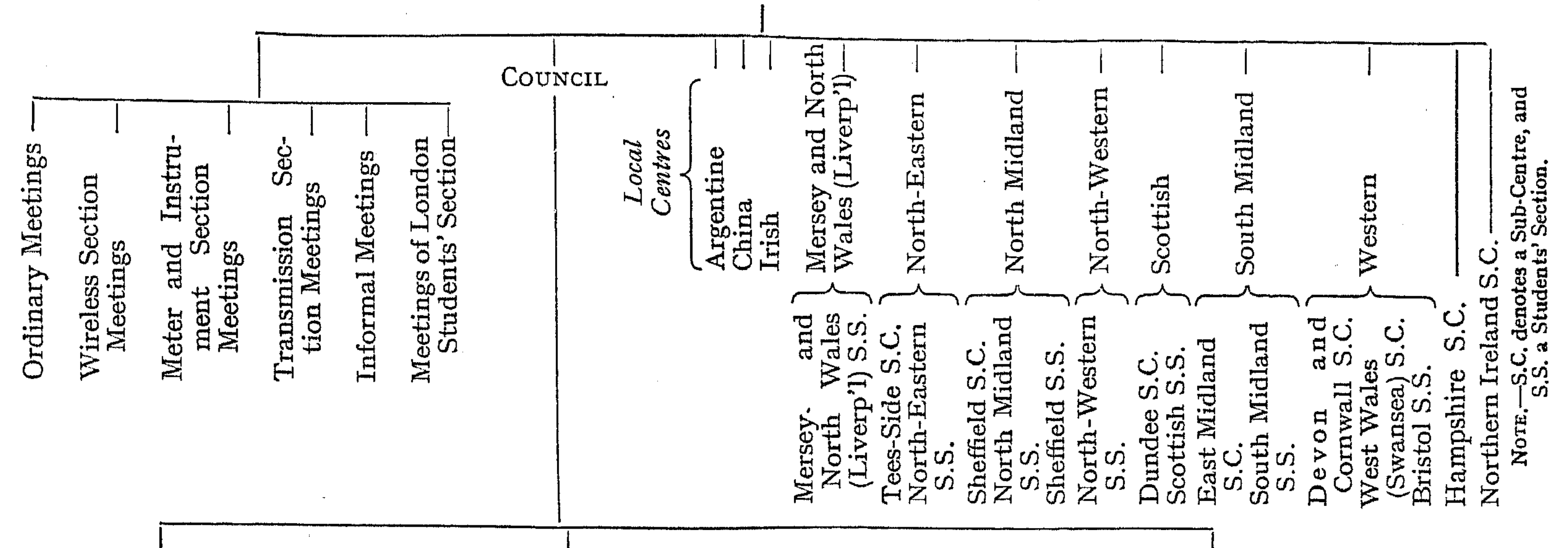
Meetings

The following is a list of the meetings held during the past 12 months:—

Ordinary Meetings	17
Annual General Meeting	1
Annual General Meeting (Benevolent Fund)	1
Wireless Section	10
Meter and Instrument Section	8
Transmission Section	7
Informal Meetings	16
Council Meetings	14
Local Centres:	
Irish	9
Mersey and North Wales (Liverpool)	12
North-Eastern	14
North Midland	13
North-Western	13
Scottish	12
South Midland	10
Western	10
Local Sub-Centres:	
Devon and Cornwall	7
Dundee	7
East Midland	9
Hampshire	9
Northern Ireland	11
Sheffield	7
Tees-Side	8
West Wales (Swansea)	7
Students' Sections:	
Bristol	10
Liverpool	12
London	15
North-Eastern	11
North Midland	12
North-Western	10
Scottish	14
Sheffield	9
South Midland	11
Committees:	
Benevolent Fund	9
Electrical Engineers' Ball	8
Committees—*continued.*	
Education and Examinations	10
Finance	12
General Purposes (and Sub-Committees)	17
Informal Meetings	6
Local Centres	1
Membership	10
Meter and Instrument Section (and Sub-Committees)	24
National Certificates (England)	4
National Certificates (Scotland)	2
Operating Theatres Electrical Apparatus (and Sub-Committees)	3
Overseas Activities	2
Papers (and Sub-Committees)	10
Scholarships	1
Science Abstracts (and Sub-Committee)	3
Ship Electrical Equipment (and Sub-Committees)	14
Transmission Section (and Sub-Committees)	15
Wireless Section (and Sub-Committees)	18
Wiring Regulations (and Sub-Committees)	29
Other Committees	21
Total	555

APPENDIX C

THE INSTITUTION OF ELECTRICAL ENGINEERS



Note.—S.C. denotes a Sub-Centre, and S.S. a Students' Section.

Committees of Council

- Education and Examinations
- Finance
- General Purposes
- Library and Museum
- Membership
- Papers

Special Committees

- Benevolent Fund
- Earthing to Water Mains (Joint)
- Electrical Engineers' Ball
- Electricity (Supply) Regulations
- Faraday Medal and Honorary Membership Advisory
- Informal Meetings
- International Relations
- Local Centres
- Meter and Instrument Section
- Model General Conditions
- Operating Theatres Electrical Apparatus
- Overseas Activities
- Patent Law
- Scholarships
- Science Abstracts
- Ship Electrical Equipment Regulations
- Transmission Section
- Wireless Section
- Wiring Regulations
- *Technical Committees*
  - Applications and Plant
  - Electricity in Mines
  - Electrochemistry and Electrometallurgy
  - Power Stations and their Equipment
  - Radiological and Electromedical Apparatus
  - Telegraphs and Telephones
  - Traction, including Railways
- *Overseas Committees*
  - Ceylon
  - India (Bombay, Calcutta, Lahore, and Madras)
  - New South Wales
  - Queensland
  - South Australia
  - Victoria and Tasmania
  - Western Australia
  - New Zealand
  - Transvaal

Bodies on which the Institution is Represented

- Bristol University
- British Cast Iron Research Association
- British Electrical and Allied Industries Research Association
- British Electrical Development Association, Committee on Rural and Agricultural Electrification
- British National Illumination Committee of the International Illumination Commission
- British Standards Institution
- Building Industries National Council, Advisory Committee on Building Acts and Bye-laws and Committee on Magnesite Composition Floors and Dadoes
- City and Guilds of London Institute
- Council for the Preservation of Rural England
- Electrical Association for Women
- Engineering Joint Council
- Engineering Joint Examination Board
- Engineering Public Relations Committee
- H.T. Conference, Paris, British National Committee
- Imperial College of Science and Technology, Governing Body
- Imperial Minerals Resources Conference, Copper Committee
- Institute of Industrial Administration, Examinations Advisory Council
- Institute of Metals, Corrosion Research Committee
- Institution of Civil Engineers, Engine and Boiler Testing Committee
- Institution of Civil Engineers, Earthing to Water Mains Sub-Committee
- International Association for Testing Materials
- International Electrotechnical Commission, British National Committee
- Joint Committee on Engineering Co-operation Overseas
- Joint Committee on Materials and their Testing
- Joint Committee of The Institution of Civil Engineers and the E.R.A. for research on Earthing to Water Mains
- Joint Fuel Committee
- League of Nations Health Organization, Committee on Health and Comfort Conditions in Housing
- Loughborough Technical College, Advisory Committee
- Manchester Regional Advisory Council for Technical and other forms of Further Education
- Metalliferous Mining (Cornwall) School, Governing Body
- Ministry of Labour, Central Register Advisory Council
- National Certificates and Diplomas in Electrical Engineering, Joint Committees for
- National Committee on Physics (Royal Society)
- National Committee on Scientific Radio (Royal Society)
- National Physical Laboratory, General Board
- National Register of Electrical Installation Contractors
- National Smoke Abatement Society
- Professional Classes Aid Council
- Royal Engineer Board
- Science Museum, South Kensington, Advisory Council
- Town Planning Institute, Committee on Overhead Transmission Lines
- Union of Lancashire and Cheshire Institutes, Panel for Engineering
- University College, Nottingham, Electrical Engineering Advisory Committee
- War Office Mechanization Board
- Women's Engineering Society
- World Power Conference, British National Committee

THE INSTITUTION OF ELECTRICAL ENGINEERS

REVENUE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1938.

Dr. EXPENDITURE.

Year ended 31 Dec., 1937 £ s. d.		£ s. d.	£ s. d.
	To MANAGEMENT:—		
	Salaries and Wages	17,385 6 8	
	Staff Provident Scheme	1,382 1 0	
	National Insurance	139 19 6	
	Audit Fee	120 15 0	
	Printing	739 18 3	
	Stationery and Office Requisites	708 7 5	
	Addressing Machine Requisites	49 6 9	
	Postage of Correspondence and Notices	1,094 6 8	
	Telephone	133 12 6	
	Travelling Expenses	292 2 6	
22,121 0 7			22,045 16 3
	,, INSTITUTION BUILDING:—		
	Ground Rent	2,201 0 0	
	Rates	3,250 7 1	
	Heating	1,117 8 9	
	Lighting and Power	506 12 7	
	Insurance	216 1 7	
	Transferred to Repairs Suspense Account	1,000 0 0	
	Alterations to upper portion of Building	410 11 10	
	Household Requisites and Cleaning	698 15 7	
		9,400 17 5	
	Less Rents from Tenants	5,525 0 0	
3,612 6 3			3,875 17 5
672 19 1	,, FURNITURE AND FITTINGS (Repairs and Renewals)		253 10 8
	,, JOURNAL:—		
	Printing	8,685 9 10	
	Postage	3,515 1 7	
	Wrappers and Envelopes	459 9 5	
		12,660 0 10	
	Less Sales and Advertisements	3,726 13 1	
7,307 7 5			8,933 7 9
65 15 0	,, PROCEEDINGS OF THE WIRELESS SECTION (Printing, Postage, etc.: *less* Sales)		115 19 6
572 17 6	,, STUDENTS' QUARTERLY JOURNAL (Editing, Printing, Postage, etc.: *less* Sales)		613 19 7
124 14 11	,, LENDING LIBRARY (Books, Printing, Postage, etc.)		153 11 0
	,, SCIENCE ABSTRACTS:—		
	Abstracting, Editing, Printing, Postage, etc.	5,502 4 10	
	Less Subscriptions, Sales and Advertisements	5,312 17 1	
438 14 0			189 7 9
	,, INSTITUTION MEETINGS:—		
	Advance Proofs	462 14 8	
	Reporting	194 5 0	
	Grant to London Students' Section	72 18 4	
	Honorarium to Kelvin Lecturer	25 0 0	
	Refreshments, Assistance, etc.	515 7 2	
	Travelling Expenses of Authors of Papers	119 1 10	
	Overseas Meetings	191 8 9	
1,215 18 3			1,580 15 9
	Carried Forward		£37,762 5 8

INCOME. Cr.

Year ended 31 Dec., 1937. £ s. d.		£ s. d.	£ s. d.
45,026 1 9	By SUBSCRIPTIONS		46,821 13 2
1,317 15 0	,, ENTRANCE FEES		1,451 2 0
78 16 2	,, LIFE COMPOSITIONS		—
5,785 6 4	,, DIVIDENDS AND INTEREST		6,167 3 8
115 8 11	,, SALES OF "MODEL GENERAL CONDITIONS"		251 8 8
164 17 3	,, SALES OF "WIRING REGULATIONS"		123 18 9
4 19 5	,, SALES OF "SHIP WIRING REGULATIONS"		7 12 10
	,, EXAMINATIONS:—		
	Graduateship Examination (Candidates' Fees and Sale of Papers, *less* Examiners' Fees, Printing, etc.)	629 8 5	
	National Certificates and Diplomas (Candidates' and School Authorities' Fees, *less* Assessors' Fees, Stationery, Postage, Travelling Expenses, etc.)	833 3 10	
1,433 6 10			1,462 12 3
	Carried Forward		£56,285 11 4

REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued*

		£ s. d.	£ s. d.
	Brought Forward	..	37,762 5 8
	To Local Centres:—		
	Money Grants	4,084 7 1	
	Travelling Expenses	781 0 8	
	Faraday Lectures	517 10 9	
	Students' Lectures	130 13 1	
	Dundee Sub-Centre Library	50 3 3	
5,187 3 11			5,563 14 10
308 19 9	,, Premiums for Papers	..	304 10 11
	,, Scholarships:—		
	Ferranti Scholarship	187 10 0	
	Duddell Scholarship	337 10 0	
	Silvanus Thompson Scholarship	347 11 6	
	Special awards	75 0 0	
	Contribution to Salomons Scholarship	37 17 5	
	Contribution to David Hughes Scholarship	39 15 6	
1,372 5 5			1,025 4 5
	,, Special Grants:—		
	British Standards Institution	1,000 0 0	
	Electrical Research Association	1,000 0 0	
	National Illumination Committee	32 0 0	
	International Electrotechnical Commission, Plenary Meeting in 1938 (3rd instalment)	350 0 0	
	International Conference on High Tension Systems	32 4 6	
	Engineering Public Relations Committee	152 0 0	
	World Power Conference	100 0 0	
	Joint Committee on Materials and their Testing	10 0 0	
	International Commission on Telephonic Interference	14 9 8	
	International Engineering Congress at Glasgow	75 0 0	
	"Earthing to Water Mains" Joint Committee	50 0 0	
	Building Industries National Council	25 0 0	
2,772 6 11			2,840 14 2
21 3 0	,, Graham Bell Memorial Tablet at Edinburgh	..	—
132 19 5	,, Annual Dinner	..	121 19 9
675 13 8	,, Conversaziones	..	711 19 7
94 10 0	,, Legal Expenses	..	49 8 3
141 13 9	,, Miscellaneous Expenses	..	181 10 0
	,, Loss on exchange on Overseas Deposits remitted to London		378 19 5
46,838 8 10			48,940 7 0
277 12 2	,, Amount Transferred to Sinking Fund (Premiums for Redemption of Cost of Building and Lease)	277 12 2	
6,810 10 8	,, **Balance carried to Balance Sheet**	7,067 12 2	
7,088 2 10			7,345 4 4
53,926 11 8			£56,285 11 4

INCOME—*continued.* **Cr.**

		£ s. d.
	Brought Forward	56,285 11 4
53,926 11 8		£56,285 11 4

BALANCE SHEET, 31st DECEMBER, 1938.

Dr. LIABILITIES.

	£	s.	d.	£	s.	d.
To Uninvested Balances of Trust Funds				480	19	5
,, Sundry Creditors				5,576	8	7
,, Subscriptions received in advance				1,201	16	3
,, Repairs Suspense Account:—						
Balance at 1st January, 1938	4,264	12	3			
Amount set aside in 1938	1,000	0	0			
	5,264	12	3			
Less Expenditure on Repairs in 1938	823	5	8	4,441	6	7
Carried Forward				£11,700	10	10

ASSETS. **Cr.**

	£	s.	d.	£	s.	d.
By Institution Building and Lease:—						
Cost	73,028	6	10			
Less Reserve for Depreciation, being Surrender Values of Sinking Fund Policies	11,500	17	0	61,527	9	10
,, Sinking Fund (Surrender Values of Policies for Redemption of Cost of Building and Lease)				11,500	17	0
,, Library (exclusive of the Ronalds Library and Faraday Papers, which are held in trust):—						
As per last Balance Sheet	1,992	8	2			
Additions in 1938	268	14	4			
	2,261	2	6			
Less Depreciation (10 %)	226	2	3	2,035	0	3
,, Thompson Memorial Library (Contribution towards purchase)				1,000	0	0
,, Furniture, Fittings, and Apparatus:—						
As per last Balance Sheet	3,188	7	0			
Less Depreciation (5 %)	159	8	4	3,028	18	8
,, Sundry Debtors				2,973	2	1
,, Insurance Premiums and Sundry Payments in Advance				1,715	6	5
,, Stock of Paper, etc., for Publications				669	2	6
,, Investments (at or under cost):—						
£2,600 Natal Zululand Railways 3 % Debenture Stock	2,270	12	0			
£1,500 London, Midland and Scottish Railway 4 % Preference Stock	1,513	10	4			
£2,000 Assam Bengal Railways 3 % Stock (1931 or after)	1,548	0	6			
£750 Western Australia 4 % Stock (1942–62)	730	8	3			
£750 Union of South Africa 4 % Stock (1943–63)	742	12	0			
£35 East Indian Railway "B" Annuity (1953)	791	5	4			
£1,500 South Australia 4 % Stock (1940–60)	1,494	10	6			
£6,450 3½ % War Stock	6,306	9	0			
£19,375 4 % Funding Loan (1960–90)	15,500	0	0			
£8,700 3½ % Conversion Stock (1961 or after)	6,651	3	3			
£11,970 11s. 4 % Consolidated Stock	10,291	6	6			
£1,000 London, Midland and Scottish Railway 5 % Preference Stock (1955)	1,020	4	6			
Carried Forward	£48,860	2	2	£84,449	16	9

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.*

			£ s. d.	£ s. d.
Brought Forward				11,700 10 10
To Surplus of Assets over Liabilities:—				
Balance at 1st January, 1938			214,345 1 5	
Excess of Income over Expenditure for 1938 brought forward from Revenue Account	£7,067 12 2			
Profit on Redemption of £750 Madras and Southern Mahratta Railway 4% Debenture Stock (1938) ..	11 4 6	7,078 16 8		
Less Allocation to Supplementary Superannuation Account ..	£750 0 0			
Depreciation:—				
Library (*per contra*)	226 2 3			
Furniture, Fittings, and Apparatus (*per contra*)	159 8 4	1,135 10 7	5,943 6 1	220,288 7 6
				£231,988 18 4

W. McCLELLAND,
Honorary Treasurer.

P. F. ROWELL,
Secretary.

ASSETS—*continued.* **Cr.**

	£ s. d.	£ s. d.
Brought Forward		84,449 16 9
By Investments (at or under cost)—*contd.*		
Brought forward	48,860 2 2	
£4,500 North Metropolitan Power Station 5 % Guaranteed Debenture Stock (1957)	4,488 11 0	
£2,000 London, Midland and Scottish Railway 5 % Redeemable Debenture Stock (1952)	1,982 5 9	
£2,300 East Indian Railway 4½ % Irredeemable Debenture Stock	2,019 13 0	
£5,000 Commonwealth of Australia 5 % Stock (1945–75)	4,964 17 6	
£2,000 Tynemouth Corporation 5% Stock (1947–57)	2,025 4 0	
£2,500 Stoke-on-Trent Corporation 5 % Stock (1948–68)	2,550 6 0	
£3,500 East Indian Railway 3½ % Debenture Stock (1937)	2,475 15 6	
£5,000 Brighton Corporation 4¾% Stock (1945–75)	5,050 8 0	
£2,000 New South Wales 5¼ % Stock (1947–57) ..	2,013 19 0	
£2,600 Kenya Government 4½ % Stock (1950) ..	2,483 4 0	
£3,000 Southern Railway 4 % Debenture Stock ..	2,520 5 0	
£2,500 India 4½ % Stock (1958–68)	2,329 17 9	
£2,500 Corporation of London 4½ % Debenture Stock (1940–85)	2,462 14 0	
£3,000 Birmingham Corporation 4½ % Stock (1948–68)	2,906 11 0	
£3,000 London County 4½ % Stock (1945–85) ..	2,936 11 0	
£1,000 Bootle Corporation 4¾ % Stock (1949–59)	967 12 0	
£11,722 17s. 11d. 2¾ % Funding Loan (1952–57)..	9,888 5 10	
£2,000 Southampton Corporation 5 % Stock (1947–67)	2,027 14 0	
£2,333 London Passenger Transport Board 4½ % "A" Stock (1985–2023)	2,110 5 0	
£2,000 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)	2,080 11 0	
£2,400 Ayr County Council 5 % Stock (1947–57)	2,484 4 0	
£2,400 Union of South Africa 5 % Stock (1950–70)	2,436 4 0	
£1,000 Nyasaland Government 4½ % Guaranteed Stock (1952–72)	1,142 13 0	
£2,500 London Passenger Transport Board 5 % "B" Stock (1965–2023)	3,017 1 0	
£5,000 London County 2¾ % Consolidated Stock (1960–70)	4,811 2 6	
£5,600 3 % Funding Loan (1959–69)	5,419 19 0	
£3,000 Birmingham Corporation 3¼ % Stock (1957–62)	2,953 8 6	
£2,000 3 % Redemption Loan (1986–96)	1,842 14 0	
£2,400 Ipswich Corporation 3¼ % Stock (1964) ..	2,310 4 0	
(*Market value 31st December,* 1938, £149,904 3s. 7d.)..		135,562 2 6
,, Cash in Hands of Local Centres on 30 Sept., 1938 ..		1,397 0 5
,, Cash:—		
At Bank	1,036 10 6	
At Banks in Australia and New Zealand	9,457 14 3	
In hands of Secretary	85 13 11	10,579 18 8
		£231,988 18 4

o report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1938, and above set forth, together with Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct and the s properly drawn up so as to exhibit a true and correct view of the state of The Institution's affairs according to the best of our information and the ven to us and as shown by the books of The Institution.

ALLEN, ATTFIELD & CO., Auditors,
Chartered Accountants,
24, Martin Lane, Cannon Street, E.C.4.

1939.

SALOMONS SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	2,085	1	4	By Investments (at cost):—			
				£1,600 13s. 3d. Commonwealth of Australia 3% Stock (1955–58)	1,585	1	4
				£500 Cardiff Corporation 3% Stock (1952–55)	500	0	0
	£2,085	1	4		£2,085	1	4

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1938	100	0	0	By Dividends received in 1938	62	2	7
				,, Contribution from Institution	37	17	5
	£100	0	0		£100	0	0

DAVID HUGHES SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	2,000	0	0	By Investment (at cost):—			
				£2,045 Metropolitan Water Board (Staines Reservoirs) 3% Guaranteed Debenture Stock (1922 or after)	1,998	15	0
				,, Balance carried to Balance Sheet*	1	5	0
	£2,000	0	0		£2,000	0	0

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1938	100	0	0	By Dividends received in 1938	60	4	0
				,, Interest received in 1938	0	0	6
				,, Contribution from Institution	39	15	6
	£100	0	0		£100	0	0

PAUL SCHOLARSHIP FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	1,000	0	0	By Investments (at cost):—			
				£625 4% Funding Loan (1960–90)	500	0	0
				£518 3s. 8d. Central Electricity Board 5% Debenture Stock (1950–70)	500	0	0
	£1,000	0	0		£1,000	0	0

PAUL SCHOLARSHIP FUND (Income).

Dr.	£	s	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1938	50	0	0	By Balance (as per last Account)	21	1	8
Balance carried to Balance Sheet*	21	10	0	,, Dividends received in 1938	50	8	4
	£71	10	0		£71	10	0

* Included in the total of £480 19s. 5 l. shown on the Liabilities side of the Balance Sheet.

WILDE BENEVOLENT TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	3,049	16	2	By Investments (at cost):—			
				£1,308 London and North Eastern Railway 4% First Guaranteed Stock	1,744	3	11
				£100 London County 2¾% Consolidated Stock (1960–70)	101	8	6
				£250 New South Wales 4% Stock (1942–62)	251	6	0
				£500 3½% War Stock	501	9	3
				£381 15s. 1d. 4% Funding Loan (1960–90)	300	0	0
				£200 3½% Conversion Stock (1961 or after)	151	8	6
	£3,049	16	2		£3,049	16	2

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Grants made in 1938	35	0	0	By Balance (as per last Account)	22	10	3
,, Balance carried to Balance Sheet*	91	9	9	,, Dividends received in 1938	103	13	5
				,, Interest received in 1938	0	6	1
	£126	9	9		£126	9	9

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	1,700	0	0	By Investment (at cost):—			
				£2,000 3½% War Stock	1,700	0	0
	£1,700	0	0		£1,700	0	0

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Grants made in 1938	50	0	0	By Balance (as per last Account)	52	10	0
,, Balance carried to Balance Sheet*	72	10	0	,, Dividends received in 1938	70	0	0
	£122	10	0		£122	10	0

PAGE PRIZE FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	100	19	5	By Investments (at cost):—			
				£50 3½% War Stock	50	19	5
				£51 16s. 4d. Central Electricity Board 5% Debenture Stock (1950–70)	50	0	0
	£100	19	5		£100	19	5

PAGE PRIZE FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Cost of Prize awarded in 1938	10	0	1	By Balance (as per last Account)	15	0	2
,, Balance carried to Balance Sheet*	9	6	1	,, Dividends received in 1938	4	6	0
	£19	6	2		£19	6	2

THORROWGOOD SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	1,000	0	0	By Investment (at cost):—			
				£1,005 Agricultural Mortgage Corporation 5% Debenture Stock (1959–89)	1,000	0	0
	£1,000	0	0		£1,000	0	0

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* Included in the total of £480 19s. 5d. shown on the Liabilities side of the Balance Sheet.

THORROWGOOD SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1938	50	0	0	By Balance (as per last Account)	52	0	1
,, Balance carried to Balance Sheet*	51	6	3	,, Dividends received in 1938	49	6	2
	£101	6	3		£101	6	3

SWAN MEMORIAL SCHOLARSHIP FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last account)	2,968	12	4	By Investments (at cost):—			
				£1,000 Sunderland Corporation 5% Stock (1946–56)	1,116	13	0
				£640 Sunderland Corporation 5% Stock (1950–60)	728	8	0
				£1,135 17s. 9d. 3½% Conversion Stock (1961 or after)	1,123	11	4
	£2,968	12	4		£2,968	12	4

SWAN MEMORIAL SCHOLARSHIP FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholars in 1938	120	0	0	By Balance (as per last Account)	9	12	4
,, Balance carried to Balance Sheet*	9	1	8	,, Dividends received in 1938	119	9	4
	£129	1	8		£129	1	8

WILLIAM BEEDIE ESSON SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	3,006	2	6	By Investments (at cost):—			
				£1,500 3½% War Stock	1,603	2	6
				£200 New Zealand 5% Stock (1949) ..	233	0	0
				£250 St. Helen's Corporation 5% Stock (1950–70)	293	15	0
				£250 Sunderland Corporation 5% Stock (1950–60)	293	15	0
				£250 Birmingham Corporation 5% Stock (1946–56)	291	5	0
				£250 Grimsby Corporation 5% Stock (1950–60)	291	5	0
	£3,006	2	6		£3,006	2	6

WILLIAM BEEDIE ESSON SCHOLARSHIP TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount paid to Scholar in 1938	166	0	0	By Balance (as per last Account)	211	11	4
,, Balance carried to Balance Sheet*	156	17	5	,, Dividends received in 1938	111	6	1
	£322	17	5		£322	17	5

SUPPLEMENTARY SUPERANNUATION ACCOUNT.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	3,232	19	7	By Investment (at cost):—			
,, Amount allocated in 1938	750	0	0	£3,866 11s. 6d. 3½% War Stock	4,043	4	9
,, Dividends received in 1938	127	18	5	,, Balance carried to Balance Sheet*	67	13	3
	£4,110	18	0		£4,110	18	0

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* Included in the total of £480 19s. 5d. shown on the Liabilities side of the Balance Sheet.

ANNUAL DINNER, 1939

The Annual Dinner of The Institution was held at Grosvenor House, Park Lane, London, on Thursday, 9th February, 1939, when the President, Dr. A. P. M. Fleming, C.B.E., M.Sc., presided over a gathering numbering 1 152. Among those present were: The Rt. Hon. Sir John Anderson, G.C.B., G.C.S.I., G.C.I.E., M.P. (*Lord Privy Seal*); The Rt. Hon. the Earl of Dudley, M.C. (*President, Iron and Steel Institute*); The Rt. Hon. the Earl of Lytton, K.G., P.C., G.C.S.I., G.C.I.E. (*President, British Electrical Development Association*); The Rt. Hon. the Viscount Falmouth; The Rt. Hon. Viscount Stonehaven, P.C., G.C.M.G., D.S.O., LL.D. (*President, Institution of Naval Architects*); The Rt. Hon. and Rt. Rev. A. F. Winnington Ingram, K.C.V.O., D.D., LL.D. (*Lord Bishop of London*); Sir Leonard Browett, K.C.B., C.B.E. (*Permanent Secretary, Ministry of Transport*); Sir Stanley V. Goodall, K.C.B., O.B.E.; Sir Cyril Hurcomb, K.C.B., K.B.E. (*Chairman, Electricity Commission*); Sir Edward Crowe, K.C.M.G.; Sir T. St. Quintin Hill, K.C.M.G., O.B.E. (*Comptroller-General, Overseas Trade Department*); Sir Montague Hughman; Sir George Lee, O.B.E., M.C. (*Past-President, I.E.E.; Engineer-in-Chief, G.P.O.*); Sir Robert H. Pickard, D.Sc., F.R.S. (*President, Institute of Chemistry; Vice-Chancellor, London University*); Sir Felix Pole; Colonel Sir Thomas F. Purves, O.B.E. (*Past-President*); Sir Albert Seward, F.R.S. (*President, British Association for the Advancement of Science*); Sir Maurice Simpson, C.S.I.; Mr. P. M. J. Ailleret (*I.E.E. Local Hon. Secretary for France; Secretary, Société Française des Électriciens*); Colonel A. S. Angwin, D.S.O., M.C. (*Member of Council*); Dr. E. F. Armstrong, F.R.S. (*Member of Council, British Standards Institution*); Mr. Ll. B. Atkinson (*Past-President; Honorary Member*); Mr. E. Bruce Ball (*Vice-President, Institution of Mechanical Engineers*); Mr. W. H. Ballantyne (*President, Chartered Institute of Patent Agents*); Mr. J. R. Beard, M.Sc. (*Vice-President*); Mr. W. J. E. Binnie, M.A. (*President, Institution of Civil Engineers*); Mr. A. C. Bostel (*Hon. Secretary, Sheffield Sub-Centre*); Prof. W. L. Bragg, O.B.E., M.C., D.Sc., F.R.S. (*Cavendish Professor of Experimental Physics, Cambridge University*); Dr. L. G. Brazier (*Member of Council*); Mr. W. A. S. Calder (*Deputy President, Society of Chemical Industry*); Mr. L. H. A. Carr, M.Sc.Tech. (*Hon. Secretary, North-Western Centre*); Mr. E. Graham Clark (*Secretary, Institution of Civil Engineers*); Mr. K. C. Coop, B.Eng. (*Hon. Secretary, North Midland Centre*); Mr. J. G. Craven (*Past-Chairman, North Midland Centre*); Mr. E. G. Culpin, F.R.I.B.A., J.P. (*Chairman, London County Council*); Dr. C. G. Darwin, M.C., Sc.D., F.R.S. (*Director, National Physical Laboratory*); The Rt. Rev. P. F. Delacour de Labillière (*Dean of Westminster*); Mr. J. S. Duncan, C.B.E. (*Acting High Commissioner for the Commonwealth of Australia*); Dr. P. Dunsheath, O.B.E., M.A. (*Member of Council*); Mr. R. N. Eaton (*Hon. Secretary, Irish Centre*); Lieut.-Col. K. Edgcumbe, T.D. (*Past-President*); Prof. A. C. G. Egerton, M.A., F.R.S. (*Secretary, Royal Society*); Mr. H. S. Ellis (*Chairman, Western Centre*); Mr. C. E. Fairburn, M.A. (*Member of Council*); Mr. H. Faulkner, B.Sc. (*Chairman, South Midland Centre*); Mr. W. Fennell (*Chairman, North-Western Centre*); Mr. S. Flemons (*Chairman, China Centre*); Mr. A. J. Gill, B.Sc.(Eng.) (*Chairman, Wireless Section*); Mr. P. Good (*President, Illuminating Engineering Society*); Mr. J. S. Highfield (*Past-President*); Mr. A. G. Hiscock (*Hon. Secretary, Hampshire Sub-Centre*); Mr. F. Hodges, J.P.; Mr. H. Hooper (*Past-Chairman, South Midland Centre*); Mr. W. D. Horsley (*Past-Chairman, North-Eastern Centre*); Mr. P. V. Hunter, C.B.E. (*Past-President*); Prof. R. O. Kapp, B.Sc. (*Member of Council*); Mr. J. M. Kennedy, O.B.E. (*Past-President, I.E.E.; Deputy Chairman, Electricity Commission*); Mr. G. A. Kysh (*Asst. Secretary, North-Eastern Centre*); Mr. H. C. Lamb (*President, Incorporated Municipal Electrical Association*); Mr. E. M. Lee, B.Sc. (*Member of Council*); Mr. E. Leete (*Member of Council*); Mr. J. McCandless, M.Sc. (*Hon. Secretary, Northern Ireland Sub-Centre*); Mr. W. McClelland, C.B., O.B.E. (*Honorary Treasurer*); Prof. E. W. Marchant, D.Sc. (*Past-President*); Mr. S. W. Melsom (*Member of Council*); Mr. R. B. Mitchell (*Hon. Secretary, Scottish Centre*); Mr. E. L. Morland [*Chairman, Mersey and North Wales* (*Liverpool*) *Centre*]; Air Commodore C. W. Nutting, O.B.E., D.S.C. (*Director of Signals, Air Ministry*); Col. G. D. Ozanne, M.C. (*Vice-Chairman, Radio Manufacturers' Association*); Mr. W. Parry, M.Eng. [*Hon. Secretary, Mersey and North Wales* (*Liverpool*) *Centre*]; Dr. C. C. Paterson, O.B.E. (*Past-President, I.E.E.; President, Institute of Physics*); Mr. R. H. Rawll (*Hon. Secretary, South Midland Centre*); Prof. E. K. Rideal, F.R.S. (*President, Faraday Society*); Mr. C. Rodgers, O.B.E. (*Member of Council*); Mr. P. J. Robinson, M.Eng. (*Member of Council*); Dr. A. Russell, M.A., D.Sc., F.R.S. (*Past-President; Honorary Member*); Mr. W. E. Schall, B.Sc., F.Inst.P. (*President, British Institute of Radiology*); Mr. H. Shaw (*Hon. Secretary, Tees-Side Sub-Centre*); Mr. S. R. Siviour (*Chairman, Transmission Section*); Brigadier H. Clementi Smith, D.S.O. (*Colonel Commandant, Royal Corps of Signals*); Mr. Roger T. Smith (*Past-President*); Mr. A. E. Tanner (*Chairman, British Electrical and Allied Industries Research Association*); Mr. C. S. Taylor (*Past-Chairman, China Centre*); Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng. (*Past-President*); Mr. C. R. Westlake (*Member of Council*); Mr. G. A. Whipple, M.A. (*Member of Council*); Mr. W. B. Woodhouse (*Past-President*); Mr. Johnstone Wright (*Vice-President*); Mr. A. P. Young, O.B.E. (*Member of Council*); Mr. H. T. Young (*Past-President*); and Mr. P. F. Rowell (*Secretary*).

The toasts of "His Majesty the King," and "Her Majesty the Queen, Her Majesty Queen Mary, and the other members of the Royal Family," were proposed by the President and were loyally received.

The Rt. Hon. Sir John Anderson, G.C.B., G.C.S.I., G.C.I.E., M.P. (*Lord Privy Seal*), in proposing the toast of "The Institution of Electrical Engineers" said: "It is at once an honour and a pleasure to undertake the toast of this learned Institution. Even the layman must be aware of the vast changes in our daily life which the development of electricity has brought about, but I am afraid that many of us seldom give a thought to those whose brains, talent, and invention, have placed these conveniences at our disposal. Scientists and technicians are creating our environment and are moulding our way of life. We may wonder, however, whether the invention of the internal-combustion engine has not proved very much a mixed blessing. I am thinking, of course, of the menace of air warfare, which is, unfortunately, so present in the minds of all of us to-day, and I am sure that you will pardon me if I refer for a few moments to the responsibilities which at the present time rest upon my shoulders in relation to civil defence and national service.

" One primary object of the national service campaign is to enrol for the necessary training those for whom there would, if war came, be definite tasks to perform in civil defence. Another object, not in any degree less important, is the establishment on a sure foundation in public understanding of a system by which the nation's man-power can be used to the best advantage in time of war. The main instrument of this system is what we call the schedule of reserved occupations. The object of that schedule is to set out the occupations which are so essential to the war effort of the nation that skilled people engaged in them cannot safely be allowed to withdraw themselves suddenly from those occupations at the outset of a war in order to join the Army or other forms of national defence. This is subject to two qualifications. In the first place it is not necessary in all cases to reserve all the men in these occupations. In some the skilled men are so few that all have to be reserved irrespective of age; but in most cases it is sufficient to reserve only those over a certain age, leaving the younger men free to undertake other forms of national service. Later on, many of those men who have been reserved will, however, be released for more active service when others—women, older men, and men unfit for active service—have been trained to take their places. What, then, is the peacetime significance of the schedule? It merely means this, that men who are covered by it—that is to say, men who are engaged in a reserved occupation and are over the age specified for that occupation—should not enter into obligations in peace time which would mean that they would have to give up working in that occupation in time of war. They should not volunteer now to undertake in war any form of full-time service otherwise—and this is an important qualification—than in the skilled occupation for which they are trained.

" As regards the electrical industry, the schedule reserves a number of categories of workers in that industry down to various ages for different categories. A few of the categories even require reservation down to the age of 21. Further, we are taking steps to record and marshal our reserves of technical and professional ability. This work is being undertaken by a central bureau in the National Service Department of the Ministry of Labour, working in close co-operation with the professional Institutions, and I am glad to express my acknowledgment to your Institution for the valuable collaboration that it is giving to the Government in that connection. Many of the employees in your industry will, however, not be covered by the schedule of reserved occupations. These men should be encouraged to enrol in one of the services in which they could give whole-time service in war—the auxiliary fighting forces, for example, or the auxiliary fire service, a new service which is greatly in need of men.

" As regards those covered by the schedule of reserved occupations, I want to make it quite clear that because a man is in a reserved occupation this does not mean that there is nothing for him to do under the scheme of national service. He should not undertake to perform in war any whole-time service which would take him away entirely from his own skilled occupation, but there is no reason why he should not volunteer now for some part-time service in war which will not prevent him from carrying on in working hours with his own particular job. Most of the various branches of civil defence, like the air-raid warden service, are part-time jobs, and men in reserved occupations should be encouraged to volunteer for part-time service of this kind. In civil defence the great lesson that we have to learn is that in modern warfare every civilian can play his part towards preserving the common welfare by taking some part, however small, in one of the many services designed to preserve the life of the civilian population under conditions of air warfare, and even in the last resort by merely knowing something about the conditions with which the ordinary man in the street will have to contend.

" Turning now to civil defence as distinct from national service, more progress is being made than some of the Jeremiahs would like to admit. In the sphere with which you are particularly concerned, for example, the vital importance of doing everything practicable to secure the continuity of electricity supply is widely recognized. The grid itself is an important contribution to that continuity, and a scheme has been worked out by the Electricity Commissioners, in collaboration with the Central Electricity Board and a national committee representing the supply undertakings, for a national reserve of transformers and switchgear. That is an instance of the way in which national security can be promoted in a vital industry by the co-operation of all concerned. The orders for this reserve have already been placed with manufacturers, and it should not be many months before deliveries are completed.

" As the industry is generally aware, the cost of these insurance measures, as I may call them, is being shared equally between the Government and the industry. It is being shared through equitable and convenient machinery, and the same financial arrangement will apply to certain other approved precautionary measures. You may wonder how we arrived at the 50–50 basis. The line of argument was something like this: public utility concerns—this does not apply only to electricity undertakings—occupying a monopolist, or quasi monopolist, position, have a clear duty to the public to maintain as far as possible in all contingencies the supply for which they are responsible. On the other hand, it may be said that a duty rests upon the Government to ensure the maintenance of vital public services. In these circumstances, with an overlapping duty and responsibility, the obviously reasonable and equitable thing to do was to agree to share the cost equally, and that principle is being applied in analogous cases, such as water and gas. It may be taken as certain that more favourable treatment has not been accorded, and is not likely to be accorded, by the Government in analogous circumstances to any other type of public utility service. This, of course, is quite apart from what is generally described as the " good employer " obligation—the obligation which every employer is expected to undertake, as a direct responsibility of his own, for the protection of his workmen. In the sphere of electricity supply very great progress has already been made towards the fulfilment of this obligation, and I would urge those concerns which have not yet made substantial progress in that direction to take the matter up and formulate their plans, get them approved, and proceed to carry them out as speedily as possible. You will find in the Air Raid Precautions Department of the Home Office, and in the office of the Electricity Commissioners, every willingness to afford all the technical guidance and assistance that you may desire.

" It is a great pleasure to me to be able to couple with this toast the name of your President. I first came into association with Dr. Fleming a good many years ago, when the Government were wrestling with the unemployment problem, and I have never met anyone more alert and more fertile in suggestion than he is. It therefore gives me the very greatest pleasure to come here to-night and to be able to associate him with this toast."

The President, in responding to the toast, said: " I should like to thank you, Sir John, for the very informative way in which you have proposed this toast, and to say that I greatly appreciate the over-generous terms in which you coupled my name with it. We are greatly indebted to you for your presence here to-night. We understand something of the magnitude of your task, we realize the urgency of the problem on which you are engaged, and we particularly appreciate the trouble you have taken in outlining the plans which you have in mind.

" Just 50 years ago The Institution of Electrical Engineers, which had emerged from the Society of Telegraph Engineers, held its first Annual Dinner. That occasion was also graced by the presence of an eminent member of His Majesty's Government, Lord Salisbury, who was then in charge of foreign affairs. In proposing the toast of The Institution, Lord Salisbury said that the Foreign Office, which he represented, positively existed by virtue of the electric telegraph and that the work of all the Chancelleries of Europe was practically conducted by the light of that great science. Such discoveries as the electric telegraph had an influence infinitely more powerful—not only upon the large collective destinies but upon the daily life and experience of multitudes of human beings—than even the careers of the greatest conquerors or the devices of the greatest statesmen. The electric telegraph had assembled all mankind upon one great plane, where they could see everything that was done and hear everything that was said and judge of every policy that was pursued at the very moment when these events took place. He also said that another aspect of electrical science had been developed and promised great benefits to the community of industrious and labouring men—facility for the distribution of power which would enable mankind to be more happy and more contented.

" It is significant that 50 years later at our Annual Dinner and in the presence of a Minister of the Crown we electrical engineers are again in a position to render assistance of inestimable value in the troublesome time with which we are faced. I venture to assert that there is no organized body of civilians comparable with this Institution in so far as the value of their accumulated scientific and technical knowledge and experience is concerned, knowledge that is of particular value and importance in national defence. That experience ramifies into every one of the fighting services; it concerns itself with communication and transport; it deals with the vital question of power supply, without which the defences of the country could not be sustained; and above all it enters directly and indirectly into the production of every kind of munition and equipment for defence.

" Throughout its history The Institution has maintained close co-operation with the defence forces. Five of its eight founder members were Service men. In 1896 The Institution received the thanks of the War Office for its offer to render available for purposes of national defence the technical skill of its members. It formed a Volunteer Corps, which in 1900 took part in the Boer War under the command of our veteran member, Colonel Crompton. At the outbreak of the Great War The Institution at once placed itself wholly and unreservedly at the service of the King and Empire. I am sure that in any future need The Institution will not be found wanting in its service for national defence—in fact at this present time your Council is co-operating closely with the Ministry of Labour in an endeavour to classify the various outlets for the knowledge and experience of our members. Later we shall send out to members a questionnaire which we hope all will complete, so that should the need unhappily arise the knowledge and experience of the members of The Institution may be most effectively utilized.

" The history of our Institution is effulgent with adventure and romance. Scientific discovery, technical development, and practical application, have followed each other with bewildering rapidity in a multitude of directions. Electrical science has extended from communications and power supply to every industry, and has resulted in the great aggregation of power supply now controlled by the grid; and under modern developments we have the great system of telecommunication, which has brought new industries into our midst.

" All the great technical Institutions have one feature in common; the members pool for the common good their knowledge and experience. They do it by papers, discussions, etc., and it is out of that pool of knowledge that development comes. In this connection I want to pay a tribute to the technical Press, by means of which new scientific knowledge, new technical developments, and new applications, can be rapidly and readily placed before the student and the engineer.

" The conduct of our Institution is something like that of a great industrial organization, and, like industrial organizations and like men, Institutions are affected by the condition of the times. In hard times they grow strong and virile; the prosperous times are the dangerous times when vigilance relaxes and virility fades out. We have survived good and bad times alike. The policy of our Institution was shaped by men of vision. The Institution has been kept free from commercialism, and its aim has always been to foster those underlying factors which are so important both in our profession and in the great industry with which we are associated. It has fostered scientific research; it has assisted in standardization; it has co-operated with the Board of Education in establishing a basis of technical education for entrants into the industry. It has also taken in hand the practical training of young engineers. By the introduction of rules for guidance notably in connection with wiring, it has assisted the industry when matters of dispute and contention have arisen. It has also co-operated closely with electrical organizations and institutions throughout the world. It has carried out this policy wisely, with discernment, and with the dignity that befits a great Institution.

" Sir John has referred at length to national defence, and we support him whole-heartedly in the need for vigilance and for being prepared for whatever emergency may arise. In the meantime, however, it is essential that we should carry on with undiminished energy and enthusiasm the regular business of our profession and the industry with which we are associated. Particularly is it necessary to strive to hold our own in overseas markets—markets which to-day are being vigorously attacked by foreign competitors. In this respect it is notable that 25 years ago much of the important plant installed in this country was made overseas. To-day the tables have been turned, and it is interesting to note that, although the export business of this country as a whole diminished last year, the electrical exports increased. That position is due largely to the foresight of electrical manufacturers, who, nearly a generation ago, established themselves co-operatively in a strong position in this country so as to strengthen their attack on the overseas markets. It is also due to the fact that technical education has improved greatly, and that much more attention is paid to the practical training of our young engineers, so that to-day the technical level of the personnel of our industry is amazingly high, and is not surpassed in any other country.

" The work of our Institution is carried out by our excellent and very hardworking staff, and it is with great regret that I have to remind you of the loss we shall sustain by the resignation, at the end of this session, of Mr. Rowell, who has been our Secretary for 30 years and has served The Institution for a much longer period than that. I am sure that the members at this great gathering would like me to assure both Mr. and Mrs. Rowell that when they go into retirement they will carry with them our unfailing affection and esteem. We hope that they will have many years of happy leisure.

" The future of The Institution is affected by two essential considerations. One is the fact that there is a continual development of new scientific knowledge which in time attains technical significance and results in applications of value to the community. The expansion of the industry and the consequent growth of The Institution will depend on the efficiency with which we are able to avail ourselves of such new scientific discoveries. The other consideration is that of the rising generation of engineers. From a lifelong association with young engineers, some of whom I have seen grow from the Student class to full Corporate Membership and to eminence in the profession, and from contact with others at various stages of this progressive development, I have no doubt whatever that the future of The Institution will be in safe keeping and that there will be no diminution of its prestige.

" Again, Sir John, I thank you for the kind manner in which you proposed the toast and all of you for the enthusiastic way in which you supported it."

Mr. H. T. Young (*Past-President*) then proposed the toast of " Our Guests," to which the **Rt. Hon. the Earl of Dudley, M.C.** (*President, Iron and Steel Institute*), and **Prof. W. L. Bragg, O.B.E., M.C., D.Sc., F.R.S.** (*Cavendish Professor of Experimental Physics, Cambridge University*), responded.

A reunion was subsequently held.

DISCUSSION ON "MULTIPLE REFLECTIONS BETWEEN TWO TUNED RECEIVING ANTENNAE"*

Dr. G. H. Brown (U.S.A.) (*communicated*): The authors have presented a treatment of a tuned receiving antenna and a tuned parasitic reflector. I believe they have made the problem somewhat complex. Before taking up that aspect of the presentation, however, I wish to comment on their introductory statements. It appears that they have somewhat misinterpreted the previous work. On page 424 (vol. 83) they quote from my 1937 paper in the *Proceedings of the Institute of Radio Engineers*, but the statement attributed to me had no connection with the case of a receiving antenna with a parasitic reflector. Actually, in that particular section of my paper, I was treating the case of a single transmitting antenna (antenna 0) and a single receiving antenna (antenna 1). Just ahead of my statement concerning the weak current in antenna 1, I stated that the antennae were separated a great distance, "many miles if we wish."

Following this treatment, I did attack the problem of a receiving antenna with a parasitic reflector, taking account of the to-and-fro reflections by the method of mutual impedances. For one specific case—that of two tuned receiving antennae placed broadside to the impinging field—I obtained equation (103) in my paper, which may be rewritten thus:—

$$\frac{\bar{I}_0}{\bar{I}_0'} = \frac{1}{1 + \frac{|Z_{01}|}{R_{00}} \cos\theta_m + j\frac{|Z_{01}|}{R_{00}} \sin\theta_m} \quad . \quad . \quad (a)$$

where θ_m is the phase angle of the mutual impedance, Z_{01}, and j is the operator ordinarily used in alternating-current notation. The absolute value of equation (*a*) is

$$\left|\frac{I_0}{I_0'}\right| = \frac{1}{\sqrt{\left[\left(1 + \frac{|Z_{01}|}{R_{00}}\cos\theta_m\right)^2 + \left(\frac{|Z_{01}|}{R_{00}}\sin\theta_m\right)^2\right]}} \quad (b)$$

or

$$\left|\frac{I_0}{I_0'}\right| = \left[1 + \frac{2|Z_{01}|\cos\theta_m}{R_{00}} + \frac{|Z_{01}|^2}{R_{00}^2}\right]^{-\frac{1}{2}} \quad . \quad . \quad (c)$$

Equation (*c*) bears a striking resemblance to the authors' equation (2) when due consideration is given to sign.

Let us now turn to the circuit shown in Fig. A, which need not be considered as an antenna circuit, but any simple network. It is simply a coupled circuit, with the primary circuit impedance Z_{00}, a secondary circuit impedance Z_{11}, and a mutual impedance Z_m between circuits.

If the secondary circuit were opened or removed, the current in the primary due to the voltage E_0 is

$$\bar{I}_0' = \bar{E}_0/\bar{Z}_{00} \quad . \quad . \quad . \quad . \quad . \quad (d)$$

But, if the circuits are coupled together, this component of current will induce a current in the secondary which will be

$$\bar{I}_1' = -\bar{I}_0'\bar{Z}_m/\bar{Z}_{11} \quad . \quad . \quad . \quad . \quad . \quad (e)$$

This component of current will induce a further component in the primary which will be

$$\bar{I}_0'' = -\bar{I}_1'\bar{Z}_m/\bar{Z}_{00} = \bar{I}_0'\bar{Z}_m^2/\bar{Z}_{00}\bar{Z}_{11} \quad . \quad . \quad (f)$$

This component of current will induce current in the secondary, thus

$$\bar{I}_1'' = -\bar{I}_0''\bar{Z}_m/\bar{Z}_{11} = -\bar{I}_0'\bar{Z}_m^3/\bar{Z}_{00}\bar{Z}_{11}^2 \quad . \quad . \quad (g)$$

This component will in turn produce a current in the primary, which will be

$$I_0''' = -\bar{I}_1''\bar{Z}_m/\bar{Z}_{00} = \bar{I}_0'\bar{Z}_m^4/\bar{Z}_{00}^2\bar{Z}_{11}^2 \quad . \quad . \quad (h)$$

We could keep on along this line indefinitely, securing a second-order term, a third-order term, a fourth-order term, etc. Then to get the current in the primary circuit, we add equations (*d*), (*f*), (*h*), and so on, to secure

$$\bar{I}_0 = \bar{I}_0'\left[1 + \frac{\bar{Z}_m^2}{\bar{Z}_{00}\bar{Z}_{11}} + \frac{\bar{Z}_m^4}{\bar{Z}_{00}^2\bar{Z}_{11}^2} + \frac{\bar{Z}_m^6}{\bar{Z}_{00}^3\bar{Z}_{11}^3} + \ldots\right] \qquad (i)$$

This is the method used by the authors in treating the coupled antennae.

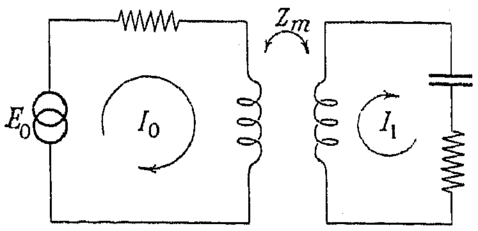

Fig. A

However, we may treat the circuit of Fig. A in another fashion. Let us write Kirchoff's law for the two circuits.

Then $$\bar{E}_0 = \bar{I}_0\bar{Z}_{00} + \bar{I}_1\bar{Z}_m \quad . \quad . \quad . \quad . \quad (j)$$

and $$0 = \bar{I}_0\bar{Z}_m + \bar{I}_1\bar{Z}_{11} \quad . \quad . \quad . \quad . \quad (k)$$

Solving these simultaneous equations, we find

$$\bar{I}_0 = \frac{\bar{E}_0 Z_{11}}{Z_{00}Z_{11} - Z_m^2} \quad . \quad . \quad . \quad . \quad (l)$$

Dividing (*l*) by (*d*),

$$\frac{I_0}{I_0'} = \frac{Z_{00}Z_{11}}{Z_{00}Z_{11} - Z_m^2} \quad . \quad . \quad . \quad . \quad (m)$$

Dividing numerator and denominator of (*m*) by $Z_{00}Z_{11}$,

$$\frac{I_0}{I_0'} = \frac{1}{1 - (Z_m^2/Z_{00}Z_{11})} \quad . \quad . \quad . \quad . \quad (n)$$

That equation (*n*) is identical with (*i*) is apparent when it is remembered that

$$1/(1-x) = 1 + x + x^2 + x^3 + x^4 + \ldots \quad . \qquad (o)$$

Whether antennae with distributed constants or lumped circuits are involved, the problem is the same. The method of mutual impedances as advanced by Carter is quite adequate to take care of the "to-and-fro" effect. In principle, the method of mutual impedances is the same as the method proposed by Prof. Palmer and Messrs. Abson and Barker. I much prefer the simplicity of the method of mutual impedances.

Prof. L. S. Palmer and **Messrs. W. Abson** and **R. H. Barker** (*in reply*): Our statement concerning the currents in Dr. Brown's antennae 0 and 1 is correct as long as the distance between the antennae is such that antenna 1 can be considered to be a parasitic antenna to antenna 0. It is, of course, true that the current in 1 will be negligibly small compared with that in 0 when the distance has been increased to such an extent that 1 can no longer be considered as a parasitic antenna to 0 but has become a distant receiving antenna. Dr. Brown's statement correctly referred to the latter condition, whilst ours referred to the former, and thus we inadvertently gave a wrong impression in our quotation from Dr. Brown's paper.

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* Paper by Prof. L. S. PALMER and Messrs. W. ABSON and R. H. BARKER (see vol. 83, page 424).

Concerning our method of treatment, although we feel that Dr. Brown's method of mutual impedances is more elegant mathematically, it is not very much shorter or simpler than our method of multiple reflections when applied to the general case of two antennae in a plane at any angle θ to the direction of wave propagation. This is shown below.

On the other hand, the physical picture resulting from our method of multiple reflections enables one to visualize that the approximations which we both make depend on the number of to-and-fro reflections which are taken into account in order to attain a required degree of accuracy. Dr. Brown's method does not readily lend itself to varying degrees of approximation. Consequently, if the required accuracy can be obtained by considering only one reflection (as when comparing calculated and measured critical antennae spacings) then our method is the simpler. Dr. Brown's method of mutual impedances, when applied to the general case of two similar tuned receiving antennae, is as follows, and may be compared with that given in our paper.

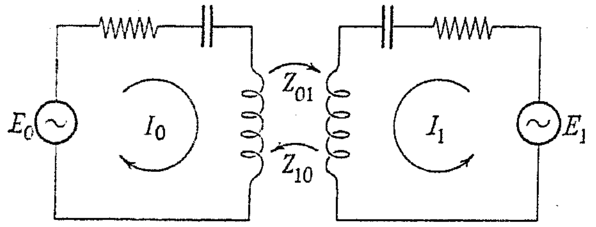

Fig. B

Two antennae, each receiving radiation from a distant transmitter, and each acting as a parasitic reflector to the other, can be represented by the circuit shown in Fig. B, where E_0 and E_1 are the instantaneous potentials due to the transmitter. For parallel radiation the magnitudes $|E_0|$ and $|E_1|$ are equal and E_1 lags behind E_0 by $\alpha = (2\pi D \cos\theta)/\lambda$, where D is the distance between the antennae, and θ is the angle between the plane containing the antennae and the direction of wave propagation.

Z_{00} = impedance of antenna 0.

I_0 = instantaneous value of the current in 0 when 1 present.

I_0' = instantaneous value of the current in 0 when 1 absent.

$= E_0/Z_{00}$

Z_{01} = impedance of radiation coupling between 0 and 1.

Z_{11}, I_1, I_1', Z_{10}, are the corresponding quantities for antenna 1.

Kirchoff's laws for the circuit are then:—

$$E_0 = I_0'Z_{00} = I_0Z_{00} + I_1Z_{01}$$
$$E_1 = I_1'Z_{11} = I_1Z_{11} + I_0Z_{10}$$

Eliminating I_1 from these equations and remembering that $Z_{01} = Z_{10}$, we get

$$I_0Z_{00}Z_{11} - I_0Z_{01}^2 = I_0'Z_{00}Z_{11} - I_1'Z_{11}Z_{01} \quad . \quad . \quad (p)$$

For two identical tuned antennae

$$Z_{00} = Z_{11} = R_{00} + jX_{00} = R_{00}$$

where R_{00} = resistance of 0, and X_{00} = reactance of 0 for the wavelength under consideration.

Also let $$Z_{01} = R_{01} + jX_{01} \quad . \quad . \quad . \quad . \quad (q)$$

Furthermore

$$I_0' = |I_0'| \sin \omega t, \quad I_1' = |I_1'| \sin(\omega t - \alpha)$$

and $$|I_0'| = |I_1'|.$$

Hence (p) becomes

$$I_0(R_{00}^2 - Z_{01}^2) = R_{00}^2|I_0'| \sin \omega t - Z_{01}R_{00}|I_0'| \sin(\omega t - \alpha)$$

or $$I_0 = \frac{|I_0'| \sin \omega t}{[1 - (Z_{01}^2/R_{00}^2)]} - \frac{Z_{01}|I_0'| \sin(\omega t - \alpha)}{R_{00}[1 - (Z_{01}^2/R_{00}^2)]}$$

Using (q) we get

$$\frac{|I_0'| \sin \omega t}{\left[\left(1 - \frac{R_{01}^2 - X_{01}^2}{R_{00}^2}\right) - 2_j \frac{R_{01}X_{01}}{R_{00}^2}\right]} - \frac{(R_{01} + {}_jX_{01})|I_0'| \sin(\omega t - \alpha)}{R_{00}\left[\left(1 - \frac{R_{01}^2 - X_{01}^2}{R_{00}^2}\right) - 2_j \frac{R_{01}X_{01}}{R_{00}^2}\right]}$$

$$= |I_0'| \left[\frac{1}{\left(1 - \frac{R_{01}^2 - X_{01}^2}{R_{00}^2}\right)^2 + \frac{4R_{01}^2X_{01}^2}{R_{00}^4}}\right]^{\frac{1}{2}} \sin(\omega t - \phi)$$

$$- \frac{|I_0'|}{R_{00}}\left[\frac{R_{01}^2 + X_{01}^2}{\left(1 - \frac{R_{01}^2 - X_{01}^2}{R_{00}^2}\right)^2 + \frac{4R_{01}^2X_{01}^2}{R_{00}^4}}\right]^{\frac{1}{2}}$$

$$\sin(\omega t - \alpha - \phi + \text{arc tan } X_{01}/R_{01}) \quad (r)$$

where ϕ is the phase lag due to the denominator $(1 - Z_{01}^2/R_{00}^2)$ operating on a sine function,

arc tan $X_{01}/R_{01} = -\beta$, $(R_{01}^2 + X_{01}^2)^{\frac{1}{2}}$ is our factor A, and $1/R_{00}$ is our factor B.

Hence $$A \cos\beta = \frac{(R_{01}^2 + X_{01}^2)^{\frac{1}{2}}}{(1 + X_{01}^2/R_{01}^2)^{\frac{1}{2}}} = R_{01}$$

Thus, on neglecting $(AB)^3$ and higher powers, (r) reduces to

$$I_0 \simeq [1 + 2(AB)^2 \cos 2\beta]^{\frac{1}{2}}$$
$$.[|I_0'| \sin(\omega t - \phi) - AB|I_0'| \sin(\omega t - \phi - \alpha - \beta)]$$

which, on subtracting vectorially, becomes

$$\left|\frac{I_0}{I_0'}\right| \simeq [1 + 2(AB)^2 \cos 2\beta]^{\frac{1}{2}}[1 + (AB)^2 + 2(AB)\cos(\alpha + \beta)]^{\frac{1}{2}}$$
$$\simeq [1 + 2(AB)\cos(\alpha + \beta) + (AB)^2(1 + 2\cos 2\beta)]^{\frac{1}{2}}$$

We thus recover our general equation (4a) using Dr. Brown's method of mutual impedances.

It is of interest, and we believe of value, to have had this opportunity of discussing and comparing the two methods of attacking the problem.

DISCUSSION ON "RECENT PROGRESS IN POWER RECTIFIERS AND THEIR APPLICATIONS"*

EAST MIDLAND SUB-CENTRE, AT LOUGHBOROUGH, 25TH OCTOBER, 1938

Mr. J. P. Tucker: My experience of this subject has been limited to about 1 950 kW of glass-bulb mercury-arc rectifiers comprising 12 units of either 200 kW or 150 kW d.c. output capacity, which were used for traction purposes. Regeneration was not required, but voltage control was provided from on-load tap-changing gear on the 33 000-volt transformers serving the transmission system to which the rectifier transformers were connected.

The specification was prepared in November, 1934, and at that time there was a feeling that grid control was not sufficiently well established to warrant its adoption in preference to the efficient and already-tried method of on-load tap-changing transformers. The railway in question ran for many miles parallel with Post Office trunk overhead circuits, and there was some doubt whether voltage regulation by means of grid control would give rise to interference. I should like the author's opinion on this point.

There were no rotary convertors on this system, and therefore the question of a compounding characteristic did not arise.

As the maximum size of unit required was 200 kW, and this output could be obtained from single glass bulbs, it was decided to adopt glass-bulb rectifiers. Each rectifier embodied the normal 6-anode arrangement, being supplied from two sets of 3-phase low-voltage windings with their star point connected through an interphase transformer.

The performance from the traction point of view was perfectly satisfactory, but the Post Office telephone service was seriously hampered—so much so that, under certain conditions, it was not possible to have a telephone conversation entirely free from interference over an area of 200 square miles, and this in spite of a special clause in the specification to cover such a contingency. Experiments having as their object the suppression of the interference were conducted in conjunction with the Post Office, and finally expensive smoothing devices were designed and installed, with greatly improved results.

Within my limited experience I have neither seen a backfire nor had one reported to me. It has been explained to me that a backfire occurs when a cathode spot develops on the anode. Does the cathode spot develop during one of the brief periods when the anode is not working?

What is glow discharge, and has this anything to do with backfires?

Since a low vacuum or the presence of foreign gases in a rectifier may cause a backfire, is it fair to say that glass-bulb rectifiers are less susceptible to backfires than steel-tank rectifiers?

Is it possible to operate a rectifier from several different networks by feeding some of the anodes from one network and others from another?

I must confess that when I first saw a steel-tank rectifier, complete with exhausting pumps and all the other incidental apparatus, my immediate reaction was that the glass-bulb type was to be preferred. There is much to be said in favour of watching the performance of any equipment. I imagine that with a little experience one can learn to assess how properly a unit is operating and may even be able to diagnose an incipient fault or a failing vacuum.

I should like the author to tell us, if he can, the estimated total capacity of pumpless rectifier plant installed in this country.

Mr. B. Nuttall: The general impression I have received from the paper is that rectifier development is passing through a stage simulating that of high-power e.h.t. switchgear. In both cases, chiefly as a result of experimental work, there appear to be several ways of obtaining the desired result, and no doubt as operating experience is gathered each of the surviving designs will be found to have its own particular sphere of application: both are concerned with arc control, in the one case to direct its path and eliminate it with the least possible disturbance, and in the other to encourage its presence in a definite and ordered sequence at the system frequency. Of the two fields of study, that of the rectifier is easier of scientific application, and no doubt much valuable information could be derived by direct co-operation between the two branches of the industry concerned.

With regard to the various types of rectifier outlined in the paper, my own experience is limited chiefly to the glass-bulb type of over 12 000 kW, both for traction and for 3-wire general supply. This type was well established before English versions of the Continentally developed steelclad rectifier were produced, and it has been very satisfactory in every way.

I suggest that the usefulness of the paper would be greatly extended if the various types of rectifiers were tabulated and some indication given of their practical limits of application and of their costs, where one or more types could be installed.

Regarding the question of the size of bulbs, mentioned on page 439, I would suggest that this is limited to a maximum of 500 amperes by considerations of handling.

The flexible dipping electrode method of ignition, mentioned on the same page, is an extremely reliable device.

Turning to page 448, it is interesting to note that the author's views on the rupturing capacity of the e.h.t. rectifier transformer breaker coincide with those expressed in Mr. Lunn's paper.* It is a drawback to have two oil-circuit-breaker ratings on one switchboard, and for the glass-bulb type of rectifier I have no hesitation in saying that this contingency can be ignored. In any case, the 3-shot duty cycle of B.S.S. No. 116 gives ample margin for such a remote possibility.

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* Paper by Dr. W. G. Thompson (see vol. 83, p. 437).

On page 452 the comparison in terms of floor area is misleading, and I would suggest that a volume basis is a better one. This also applies to Fig. 13, which incidentally omits the e.h.t. switchboard. When the e.h.t. switchgear is included and double-tier glass-bulb rectifiers or gallery-mounted single-tier rectifiers are specified, the overall advantage will lie with the glass-bulb type.

I should like the author's opinion concerning the efficiency and cost of voltage regulation on the d.c. busbar by (*a*) Induction regulator with fixed tapping on the power transformer (assuming 12-phase rectification). (*b*) Grid control, which presumably involves on-load tap-changing on the power transformer.

Grid control would require resonant shunts even with 12-phase rectification, although my experience with Method (*a*) shows that an increase of transformer connections from 6 to 12 phases is sufficient.

At what percentage total load do the units of the pumpless rectifier become unstable, and how does one tell when instability has set in?

Mr. S. J. R. Allwood: I am particularly interested in the rupturing capacity of the switchgear on rectifier installations. My experience goes back to some of the earliest rectifiers in this country, working at d.c. voltages of 2 000. At that time the consequences of a backfire were not fully appreciated, with the result that when one occurred the effect on the switchgear was disastrous. A good deal of research work was consequently undertaken with a view to evolving switchgear which would give adequate protection. The difficulties experienced with the earlier type were principally due to defective glands, and with the introduction of a special type of seal and other methods, greater reliability was obtained.

The production of a rectifier of any required capacity is only a matter of cost. It is quite possible to bring the steel-tank rectifier down to capacities of 200 or 300 amperes. The glass-bulb rectifier is produced at a considerably lower price for smaller capacities, and I think this is the reason for its development.

The earlier type of glass bulb had a very short life, but an improvement in this respect has followed the development of a harder glass. I know of a glass-bulb rectifier which has actually been run for 90 000 hours. Glass-bulb rectifiers can be banked to give capacities of 1 500 or 2 000 amperes, and when they are built up into such units it is possible to replace a defective bulb without taking the unit out of service.

With reference to grid control, where this is required most is in the lower-voltager rectifiers, supplying, say, 230-volt d.c. networks. A very appreciable amount of ripple is introduced into the d.c. output unless elaborate smoothing circuits are installed. As the load on the rectifier goes down, the amount of grid control has to be increased, with the result that the percentage ripple increases. I have taken oscillograms on a plant and found that the ripple voltage can be as much as 23 per cent of the total voltage when unsmoothed.

In his verbal summary of the paper the author described two methods of grid control, the rotating-commutator method and the phase-shifting device. From the point of view of a static plant the former is surely a step in the wrong direction. I think that the phase-shifting device is the more simple of the two. The rectifiers with which I am concerned are all fitted with the phase-shifting type of regulator, and we can easily keep within a regulation of 2 or 3 per cent. I should like to know the author's opinion of the two methods of control.

Mr. N. Turner: The paper would perhaps have been more valuable had it set forth briefly the fundamental ideas behind the mercury-arc rectifier. For example, the term "grid control" makes the uninitiated think of the control given by the grid of an ordinary wireless valve.

If I were to supply a single anode in a single mercury chamber with direct current, I would, if the polarity were correct, produce a steady arc. If I inserted a grid between the anode and the mercury pool and made the voltage on the grid fluctuate by means of a tiny alternator, would the flow of current from the d.c. supply vary in sympathy, providing the arc was not extinguished?

If I put a transformer primary on the d.c. supply should I be able to draw alternating current from the secondary, and therefore be able to produce what frequency I desired? If such were the case we should have available a method of speed control for a.c. motors by the injection of various frequencies into the rotor.

[The author's reply to this discussion will be found on page 757.]

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE, AT LIVERPOOL, 7TH NOVEMBER, 1938

Prof. F. J. Teago: In February, 1920, at the University of Liverpool, we carried out our first experiments on the rectification of alternating current by means of an ordinary carbon arc burning in air and arranged as shown in Fig. F. The magnet system, fed from a d.c. supply, pre-fixed the polarity of the d.c. output terminals and switched over the arcs at the correct instants. The apparatus, having all the electrodes of carbon, was erratic in firing, and, being used on a low-voltage supply, had a low efficiency.

The present-day Marx arc, as the author points out, can function on very high voltages with a high efficiency, but suffers from the disadvantage that the polarity of the electrodes is not pre-fixed since the electrodes are exactly similar to each other.

With regard to anode material, our experience here supports the author's statement that graphite is satisfactory and that steel is unsatisfactory. We have also found that arc-lamp carbon rods are quite satisfactory for small experimental arcs.

I think that the author has done well to stress the fact that the mercury arc differs from the ordinary electrical machine in so far as its efficiency is not necessarily a function of its rated output, so that it is quite a feasible proposition to carry the total load on a bank of rectifiers in parallel.

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* *Journal I.E.E.*, 1936, vol. 78, p. 123.

I should like to ask the author what exactly is meant by the statement that an operating voltage of 20 kV implies a reverse voltage of 40 kV. Does he virtually mean by “ reverse ” voltage the p.d. which exists between any two anodes in phase opposition?

I consider that the vitreous seal has “ made ” the mercury-arc rectifier, since it has enabled real engineering jobs to be made of the electrodes and grids, which can, if necessary, be made demountable by the use of lead gaskets in tongue-and-groove joints.

Our experience here supports the author's contention that rubber seals are effective if kept cool, but we are strongly of the opinion that mercury seals, where oil is about, are not satisfactory; and I think he should have stated that soldered joints (if by this he means joints made with ordinary solder) must be kept from contact with mercury.

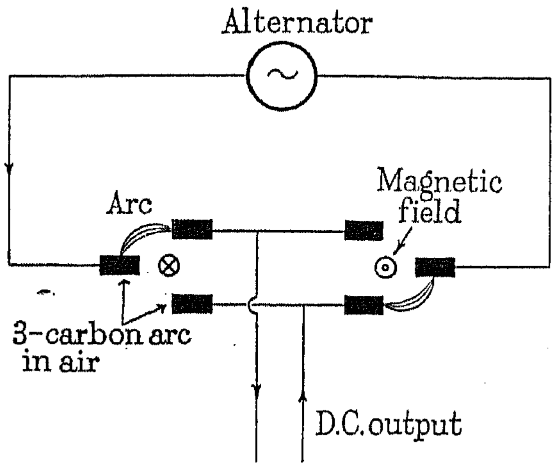

Fig. F

I think that most of us have come to the same conclusion as the author with respect to the function of grids. Formerly it was thought that grid control of voltage was likely to be a feature of mercury-arc operation, but to-day the opinion is that the main function of the grid is as a de-ionizer of the arc path.

I should like to ask the author whether he has had any experience with the high-frequency arc; it has been suggested that owing to the difficulty of de-ionizing the arc paths a frequency of 2 000 cycles per sec. may be the upper limit of successful operation.

Further, with respect to Fig. 5, I take it that the reason why the current output falls as the voltage rises is de-ionization difficulty at the higher voltages, and not heating trouble.

Again, shields are used firstly to prevent ionization spreading through the whole volume of the mercury vapour, and secondly to ensure the production of a thoroughly de-ionized arc path immediately the arc is extinguished.

With low voltages, I am not inclined to believe that the whole space does ionize, but consider that the ionization is mainly directly between the cathode and the most positive anode and is tubular in form. This probably accounts for the fact that low-voltage arcs can be operated without shields.

I should like to tell the author that we have been very successful here lately with a low-voltage, half-wave, 50-cycle Ignitron in which the igniter crystal is inserted in the centre of the main anode instead of having a separate circuit. It has two very good features: it is robust and requires a minimum of parts, and the hot spot remains absolutely fixed in the centre of the mercury pool. The general arrangement of the apparatus is shown in Fig. G.

Mr. G. W. Parkin: It would appear that the robustness of the steel-tank rectifier coupled with the simplicity of the glass-bulb type has been achieved by the satisfactory development of the pumpless air-cooled steel-tank rectifier. If the general robustness and ability to withstand shock were amply borne out in practice by this class, could not one go a step further towards the elimination of components and dispense with anode fuses, relying upon the switchgear giving more onerous service?

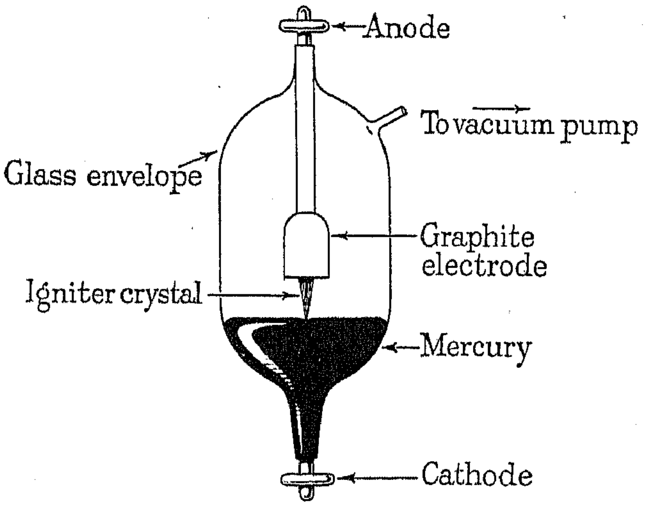

Fig. G

One is frequently assured that consequent upon the improved technique of creating and maintaining a low gas pressure in the bulb, and by careful choice of materials, backfiring has been practically eliminated. The desire, however, to retain provision for individual bulbs of a bank being so isolated in the event of internal short-circuits rather indicates that total immunity from this trouble has not yet been obtained.

I imagine that the pumpless air-cooled steel-tank rectifier will have a first cost which will compare favourably with that of the glass-bulb type, and, if so, taking into account the fact that the steel tank is capable of reconditioning whereas its glass counterpart when defective is practically valueless, the former type should strongly appeal to the consumer. I should be pleased if the author could state whether such is the case.

The Ignitron unit is a most interesting development of the single-phase mercury-arc rectifier; but apart from its high efficiency at low output voltages due to a low arc drop, and the possibility of voltage control by timing the igniter valves, are there any features likely to make it a serious competitor to the polyphase mercury-pool rectifier?

Mr. O. I. Butler: The method of ignition in the case of the pumpless steel rectifier, as illustrated in Fig. 2, is a considerable improvement on many of its predecessors with respect to the mechanical arrangement, but it appears to suffer electrically from the change. Other methods, in which the ignition rod is the moving member, necessitate more inconvenient and elaborate methods of supporting the ignition rod.

The method of Fig. 2 depends, however, upon the excitation of a solenoid to sink the steel ignition cup into the mercury of the cathode. I presume that the cup is held below the surface of the mercury during the normal working of the rectifier, in which case a constant electrical loss, inversely proportional to the resistance of the solenoid for a given applied voltage, is obtained throughout the operating time of the rectifier. Other methods require the solenoid to be excited during the initial striking only of the arc. Pumpless air-cooled steel rectifiers are not intended for large outputs, and I should like to know whether the apparent continuous loss due to the ignition solenoid is an appreciable percentage of the total losses of the rectifier. A further point which arises with this system of ignition is the possibility of failure of the solenoid during normal operation of the rectifier. The steel cup would then float at the surface of the mercury to make electrical connection between the cathode and the ignition rod, which would not improbably lead to various complications.

The statement on page 446 that " Unfortunately, the invertor is still handicapped by the fact that it injects alternating current at a leading power-factor into the network, and as a result its usefulness is practically confined to regenerative braking in traction and rolling-mill operation," can be very misleading unless it is enlarged upon. It is doubtful whether any electrical engineer would regard a machine which gives a leading power-factor to his network as an unfortunate handicap. He would be more inclined to regard it as a fortunate advantage, helping to improve the more usual lagging power-factor experienced.

It is more correct to say that the invertor functions in such a way that the current pulses, given in opposition to an applied a.c. phase voltage, attain maximum numerical value before the corresponding a.c. phase voltage. Such operation can only be obtained by grid control; and the current pulses in any one phase must never be allowed to lag the voltage of that phase, in order to avoid a short-circuit of the mercury-arc invertor with the a.c. and d.c. electromotive forces in series. This latter condition, the avoidance of lagging current pulses, is thus readily recognized as a possible handicap to the proper functioning of the mercury-arc invertor. However, it remains to point out that, despite the fact that the wave-form of the current pulses in any one phase leads the voltage wave-form of that phase, the departure of the current pulses from sinusoidal wave-shape is such as to result in energy being transferred to the a.c. network, which does not possess a leading power-factor characteristic. Hence the regenerated energy will not improve the power factor of an external a.c. network which operates at a lagging power-factor. I should be glad if the author would confirm this latter statement.

Mention is made on page 443 of a " synchronously-driven induction generator." Such a conflicting description of electrical apparatus can only lead to confusion and fail to give a clear conception of what is actually implied. An induction generator is generally recognized as an a.c. machine which, when driven by an external mechanical coupling at a speed *greater than* synchronous speed, operates as an a.c. generator. When supplied with electrical energy, the machine will operate as a motor and rotate at some speed which is *less than* synchronous speed, the actual value depending upon the load imposed on the motor. When the machine is driven by an external mechanical coupling at synchronous speed, there is no transfer of electrical energy from the machine *to* the a.c. lines. Several possible alternatives suggest themselves as to what is actually meant by the author, but in order to have a clear conception of the functioning of the timing circuit of Fig. 7 it is essential to know which of the possible alternative meanings is the correct one. Perhaps the author will clarify the matter.

Several interesting figures are given for the capacity of various surfaces for dissipating heat. Figures relating to the formation of heat at other points in the rectifier would be of interest. I should also be grateful if the author could give particulars of the quantity of mercury which leaves and returns to the cathode in unit time.

It is pointed out on page 443 that hydrogen diffusion can be prevented by using stainless steel. With regard to this subject, mention may be made of an experiment in which a seamless steel tube, with a 5-mm. thickness of wall, was degassed at a temperature of 400° C. and evacuated to such a point that a vacuum of more than 10^{-4} mm. of mercury existed in the tube.[*]

Whilst the tube remained in air the vacuum suffered no measurable depreciation, but when a portion of the tube was immersed in pure distilled water at 95° C., the presence of hydrogen gas inside the tube was detected after 8 minutes by means of a hot-wire vacuum gauge; and subsequently a maximum rate of diffusion was observed of 0·277 cm^3 per mm. of mercury per cm^2 per hour.

It is evident, therefore, that the problem of hydrogen diffusion is a very real one, and the development of high-power pumpless steel rectifiers with water cooling will require a solution which is less costly than that of the use of stainless steel. It would be interesting to know whether any other alternative methods exist for successfully avoiding hydrogen diffusion.

[The author's reply to this discussion will be found on page 757.]

NORTH MIDLAND CENTRE, AT LEEDS, 3RD JANUARY, 1939

Prof. E. L. E. Wheatcroft: In the first place I feel it is a pity that the author should not have given at the beginning of his paper a curve showing statistics of kilowatts of rectifier plant installed; for had he done so, I believe that we should have been much impressed with the growth in the use of rectifiers. Nevertheless, I cannot quite agree with his statement that were it not for rectifiers there would be hardly any direct current used; I think we must still take the view that it is the need for direct current which causes the demand for rectifiers.

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[*] *Beama Journal*, 1937, vol. 41, p. 74.

The question then reverts to that of static rectifiers versus rotating machinery. The main argument in that connection appears to be that a rotating machine needs watching. I have never been quite certain on this point; and it is, of course, a known fact that unattended automatic rotary substations have been built, and on the other hand that rectifiers have a certain amount of moving auxiliary equipment which, if it goes wrong, will lead to trouble.

I find it a matter for comment that the glass-bulb rectifier, despite little change of design over a period of some 40 years, is still holding its own with the steel-tank type. I take the view that it is very easy for an engineer who is used to metal to be unnecessarily afraid of installing apparatus involving glass. It is surprising how tough and rigid glass can be, and as an instance I would cite the case of glass triode valves used in telephone repeaters and obviously giving a very high standard of service and an extremely long and reliable life. The one disadvantage of glass is that when once sealed it is not usually possible to dismount for repairs. In compensation for this, the vacuum-tight seal makes the valve proof against interference, and, as is well known, it gives excellent long-time service. I wonder whether, therefore, the sealed-up steel-tank rectifier is not taking the worst of both worlds in having the disadvantages of permanent sealing without the simplicity of glass or the advantage that the operator can see what goes on inside.

The next point of considerable interest is the question of the economic size of rectifier. Once again the controversy of glass versus steel comes in. The idea of an economic size was proposed first by manufacturers at Pittsburg at a time when, I believe, there was a difficulty in constructing large steel-tank rectifiers. Yet for us now, when the difficulties of manufacture have been solved, there remains the question of economic size from the point of view of efficiency. It is well known that the arc drop with larger rectifiers increases considerably as compared with that of smaller units, so that it is very possible for the losses to be doubled in a single unit as compared with several smaller units. This is, of course, in direct contradiction to experience with other electrical plant, and for that reason engineers must seriously think whether their previous habits should not be reconsidered in this case.

Lastly, I am struck by the statement, made not only by the author, but by other engineers, that direct-current transmission is now dead. Direct-current transmission was introduced to us 5–6 years ago in an Institution paper,* and we found it difficult to criticize the proposals then put forward; I should like to know why d.c. transmission is now said to be uneconomical.

Mr. C. Higgens: I gather from the slides which the author showed that his personal preference is for the pumpless steel-tank type of rectifier. It appears to me that one should have an open mind as regards type, and be guided largely by the output required from the substation when making a decision.

The glass-bulb rectifier has proved remarkably reliable in spite of the obvious fragility of the bulb. Bulb-life is very much longer than any engineer accustomed to the heavier types of plant would have expected. The auxiliaries required are simple, but the output per unit is unfortunately limited to between 400 and 500 amp., continuous rating. On the other hand, the water-cooled steel-tank type is robust and can be built in very large units. Against this must be offset the increased complications attaching to vacuum pumps, water circulation, etc. Nevertheless, rectifiers of this type are exceedingly reliable, and I am inclined to the opinion that the complications attaching to the necessary auxiliaries have been somewhat exaggerated by the exponents of competitive types. Simplification, where possible, is, however, desirable, and it is for that reason that the author's description of the pumpless, steel-tank, air-cooled type of rectifier is of particular interest. This design appears to combine the main advantages of the other two types, but owing to cooling limitations there would appear to be fairly definite limits to the output per unit—the author mentions 700 amp. (i.e. only 350 kW at 500 volts). Despite the fact that many substations have been built up with numbers of small units in parallel, the existence of this current limit would appear to suggest that the economic application of the pumpless type of rectifier is confined to the medium-sized substation. Comparing the layouts shown on page 453 of the paper, provided the load factor is reasonably good the single-unit equipment appears to be the simpler and more reliable job.

As evidence regarding the performance of the water-cooled steel-tank type of rectifier, there is a particularly interesting equipment connected to the Yorkshire Electric Power Co.'s mains at the works of a well-known glass-bottle manufacturer. This is one of the earliest rectifiers of the type to be installed in this country. It is rated at 900 amp., 220 volts, and has six water-cooled anodes. The seals are of the rubber-gasket type and are under a head of mercury, as described on page 441. The equipment was installed in 1922, and operates 168 hours per week. It is still giving every satisfaction to the owners. As regards maintenance, the set has only once been overhauled, and the only renewals found to be necessary were a set of anode coolers (the old ones were showing signs of corrosion) and a set of gaskets for the seals.

I have heard very high opinions expressed regarding the pumpless type of rectifier. What I should like the author to tell us is: Apart from unexpected and abnormal defects, will the pumpless rectifier maintain its vacuum indefinitely, or is a periodical clearing-out necessary? Further, should a defect, resulting in a leak, develop in the course of service, how is it possible to determine where the leak is? The probability would appear to be that any leak would be connected with a seal. With the mercury seal and tell-tale indicator one can see at a glance which seal is in trouble. It would appear to be very difficult indeed, with the vitreous-enamel type of seal, to pick out the offender.

In the first part of his paper the author suggests that competition ceases to be between rectifier and rotating machinery and is now between different types of rectifier. This implies that there is little further need for the older types of converting plant, but I doubt whether such is the case. At 500 volts and more, the efficiencies obtainable in rectifiers make it very difficult for rotating plant to compete, but on lower voltages the arc drop is such as to bring the rectifier efficiency to below that obtainable with rotating plant. At 220 volts, for example, it would be a case of balancing low maintenance costs against increased losses, and the result would be by no means necessarily in favour of the rectifier.

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* H. Rissik: *Journal I.E.E.*, 1934, vol. 75, p. 1.

Mr. W. W. E. French: I intend to confine my remarks to the non-vacuum type of rectifier, and in particular to the mercury jet-wave rectifier.

I am glad to notice the author's encouraging remark that, in spite of the strong commercial and technical position of the mercury-arc rectifier, the almost exclusive use of vacuum equipment will not persist in the future. I make this statement because I am interested in the high-power development of the mercury jet-wave rectifier, which took a notable step forward when a testing laboratory was commissioned early in 1937 in Copenhagen for the special purpose of investigating and developing high-power mercury jet-wave equipment. As a result of the researches carried out by this testing laboratory the power which can be dealt with per commutator (or mercury jet) has been raised from 33 kW to 125 kW, at the same time the range of voltage per commutator has been raised from 200 volts to 1 000 volts. In view of this there can be little doubt that before long practical mercury jet-wave rectifiers with outputs up to 2 000 kW will be available for use in electric traction and the electrochemical industries.

The arc losses in mercury-arc rectifiers are proportional to the direct current at all voltages, and so the efficiency is comparatively low at voltages up to about 1 000 volts, and comparatively high above 1 000 volts. With the jet-wave rectifier the spark losses are roughly proportional to the product of the direct current and the d.c. voltage, and hence the efficiency will be lower than that of the mercury-arc rectifier at high voltages; but at the low and medium voltages (say, up to about 1 000 volts) the efficiency of the jet-wave rectifier will exceed that of the mercury-arc equipment. From this point of view the jet-wave rectifier is in a better position to meet and surpass the efficiencies of rotary convertors and motor convertors, which operate at about 600 volts, than the mercury-arc rectifier.

Inversion should be considered an important characteristic in the performance of this type of equipment, provided the changeover from straight rectification to inversion and back is a natural one, as with the mercury jet-wave apparatus. Whether the mercury jet-wave rectifier operates as rectifier or as invertor depends solely on the relative magnitudes of the voltages in the d.c. and the a.c. systems, and in the absence of complicated intermediate control gear such as becomes necessary with the mercury-arc rectifier if it is to function as an invertor at all. In this respect the operation of the mercury jet-wave rectifier is superior to that of the mercury-arc equipment. The importance of this property was stressed by Mr. T. S. Pick in the London discussion (vol. 83, p. 458).

I notice that the author makes the following statement regarding commutation of non-vacuum rectifiers: "The mechanical inertia associated with the moving parts of these types of rectifiers does tend to produce commutation difficulties, especially when inverted operation is attempted. Partly for this reason the application of an auxiliary to give so-called harmonic commutation has been put forward in several instances." I must contradict this statement so far as the mercury jet-wave rectifier is concerned, since its commutation as a rectifier is perfectly stable and efficient, and auxiliary devices to assist commutation are not necessary. In fact, the mercury jet-wave equipment works more efficiently and commutates better when operating as an invertor.*

Mr. W. Dundas: The development of the rectifier is largely associated with traction supplies and the desire to eliminate rotating plant, which has a somewhat lower overall efficiency. The selection of the most suitable type of rectifier depends upon the capacity and capital expenditure involved, which is a function of the space occupied by the layout, as illustrated in Fig. 13. The glass-bulb rectifier is attractive by virtue of its simplicity up to about 500 kW, but there still remains the uncertainty of the life of the bulb, apart from the risk of accidental damage. In the case of steel-tank units, trouble has been experienced with corrosion in the anode coolers and the high-vacuum pump, and attempts to overcome such trouble by chemically treating the water have not given the desired results. The use of distilled water proved effective, but did not eliminate the trouble entirely.

I should like to have the author's views on the question of protection on the d.c. side of rectifiers and on outgoing traction feeders.

Inversion would at first seem to be a desirable feature when it is a question of supplying vehicles equipped with regenerative control. Failures on relays at substations have been experienced with the potentials produced by regeneration, however, and the problem of dealing with the returned energy is not quite as simple as it would appear.

In view of the added complications to the rectifier equipment and on the vehicle itself it seems that inversion is not worth while with the low-period units supplied for traction services.

Mr. W. S. Milner: I should like to ask a question with regard to the connection of the rectifier units to the transformer. It is fairly well known that the mercury arc has a negative voltage/current characteristic, and to run two or more anodes in parallel it is therefore necessary to introduce equalizing coils; or, alternatively, to equip the transformer with a number of parallel secondary windings. I should like to know whether this latter method of connection is adopted in the case of the unit rectifiers with pumpless-type cylinders; because it seems to me that if there were six such windings on one transformer then that transformer would be cumbrous and much more expensive than the transformer feeding a single large rectifier.

[The author's reply to this discussion will be found on page 757.]

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* See J. Hartmann: *Journal I.E.E.*, 1930, vol. 68, pp. 945, 969; and W. E. French: *Electrical Review*, 1934, vol. 115, p. 77.

THE AUTHOR'S REPLY TO THE DISCUSSIONS AT LOUGHBOROUGH, LIVERPOOL, AND LEEDS

Dr. W. G. Thompson (*in reply*): In reply to Mr. Tucker, the voltage regulation by means of grid control results in the d.c. output becoming " saw toothed." For the normal range of voltage variation this ripple would not be very severe, but would require slightly larger smoothing equipment to minimize interference.

The heated spot on the anode may develop during the arcing period, but its effect becomes apparent in the final stages of commutation when the application of the reverse voltage produces emission from the spot to interfere with the normal de-ionization process in the anode arm. The glow discharge is the usual type of discharge obtained at low gas pressures with a cold current such as in a neon lamp. It is usually associated with low current values and could also be encountered in a rectifier-anode discharge immediately before an arc-back takes place.

Under normal conditions of working, backfires in steel-tank rectifiers are extremely rare. So far as water-cooled rectifiers are concerned, they are usually under much more severe duty than glass-bulb types, and a fair comparison is difficult. We do know, however, that the steel-tank pumpless rectifier is in no way inferior to the glass-bulb rectifier from the standpoint of freedom from backfire and, should a backfire occur, the steel rectifier is infinitely more robust and therefore unlikely to sustain damage.

It is possible to operate a rectifier from different networks, though naturally they would have a common point in the cathode pool. Incidentally, the auxiliary excitation of the rectifier virtually amounts to this condition, as the auxiliary anodes are excited from an independent tertiary winding or auxiliary transformer. Superficially it might appear an advantage to be able to see the arc in the rectifier, but my experience has been, with both mercury-vapour and other types of arc rectifier, that unless viewed through a stroboscope there is little of any value that can be seen, and when the trouble is actually visible it usually means shutting down the plant to take the unit out of service. Most rectifiers are required for automatic substations, and there should be no need to keep the plant under observation. The estimated total capacity of pumpless rectifiers installed is about 25 000 kW, most of it in this country.

Mr. Nuttall remarks on the correlation between arcing in switchgear and the arc produced in a rectifier. This has long been recognized by the manufacturers, and considerable co-operation takes place between the departments concerned.

I regret that it is not possible at this stage to include a table showing the scope of the different types of rectifier, as the amount of overlapping between various groups is very considerable. It would, perhaps, be easier to say that for large chemical and other process work the water-cooled rectifier remains unchallenged for currents above 4 000 amperes. Below 1 000 amperes the water-cooled rectifier appears to be no longer competitive. The pumpless steel-tank rectifier covers a wide range, including traction of all kinds, and is also suitable for industrial and general purposes down to about 250 amperes. Below this figure the glass bulb is generally preferred.

Demarcation between glass-bulb and steel-tank pumpless rectifiers is very difficult, but where a few moderate-sized units are preferable to a large number of small units the advantage would be in favour of the pumpless steel-tank type.

The question of circuit-breaker ratings has now been determined, and with the modern circuit-breaker there will be no difference between the glass-bulb and the other type of rectifier in this connection.

I do not agree that the comparison in terms of floor area is misleading, and would point out that the volume basis would show an even greater saving in favour of the pumpless steel-tank type. The relative costs of induction-regulator versus grid-control voltage regulation with on-load tap-changing gear will depend largely upon the primary supply voltage. Generally speaking, the margin of difference between the two, on the grounds both of price and of efficiency, would be small. Neither of these two items is really a deciding factor, and the decision is more likely to turn on purely technical reasons, such as speed of response, simplicity, and suitability.

The pumpless rectifier equipment is designed to give stable operation down to zero load.

I was interested in Mr. Allwood's remarks about the difficulties with the earlier types of rectifiers, and also his views on the relative cost of the units. The steel-tank pumpless rectifier can also be banked where large outputs are required, and here, again, it is also possible to change over the cylinder without taking the unit out of service; fortunately, such contingencies are extremely rare.

With regard to the two methods of grid control, namely the commutator-method and the phase-shifting device, their relative merits are not immediately apparent and much depends upon the circumstances in which grid control is going to be applied.

In reply to Mr. Turner, I am inclined to agree that many of the terms used in rectifier practice are a little indefinite in their meanings, the exact sense of which may be obvious only to engineers who are in contact with rectifier problems. We can say that in ordinary circumstances it is not possible to modulate the output of a rectifier using the grid in exactly the same manner as in a wireless valve. The position can be summed up by saying that the grid can inhibit the striking of the arc but is unable to control the arc once it has started.

Prof. Teago gives an interesting account of the work at Liverpool University. It is interesting to learn of the experiments carried out at Liverpool in connection with the igniter types of rectifier. By reverse voltage we mean the potential which exists between an anode and the cathode during the period when that anode is idle, and it is the voltage tending to restrike the arc. Prof. Teago's opinions about various features of rectifier construction are in accordance with my own experience in practice.

Though the de-ionizing action of the grids is now generally recognized as their chief function, two other effects mentioned by various authorities are, first, the subdivision and spreading of the arc so as to make greater use of the available anode surface, and secondly the thermodynamic influences resulting from the heat exchanges between the vapour and the grids. The upper limit of frequency for the operation of a mercury-arc rectifier is of the order of the figure put forward by Prof. Teago. The reason for de-rating the output of a rectifier at higher voltages lies in the difficulty of de-ionizing the arc path sufficiently fast to cope with the rapid growth of the reverse voltage. Anode shields have, in addition to their screening effect, a direct shielding function in preventing the anodes from being exposed to the vapour blast from the cathode spot.

In reply to Mr. Parkin, the more recent tendency in connection with the steel-tank pumpless rectifiers is to dispense with anode fuses where circuit conditions permit. The retention of anode fuses is not entirely a matter of vacuum preservation as suggested in the discussion, as other parts of the circuit also require protection. The igniter type has possibilities also in the matter of layout and head-room when compared with the conventional type of rectifier, though, here again, these may be more apparent than real.

I cannot accept Mr. Butler's view that the method of ignition shown in Fig. 2 is in any way inferior to other methods used. The solenoid coil is used as part of the current-limiting system for the auxiliary anode circuit and therefore represents a loss of a few watts, which loss would be present in any case, apart from this dual function of the holding-down coil. The said loss is practically a negligible proportion of the total output. The effect of the ignition cup floating to the top of the mercury during operation was investigated experimentally while the rectifier was in the development stage, and it was found to give rise to no trouble whatsoever.

The statement " injects alternating current at a leading power factor " should be explicit as it stands, when one bears in mind the distinction between " injecting " a leading current and " taking " a leading current. The question of leading power factor in the phase-displacement sense is not contingent upon the actual wave-shape of the current, which merely influences the harmonic content of the wave. Probably the case can best be explained by the fact that it is not possible without special means to operate machines which take a magnetizing current, such as induction motors, directly from an invertor. The machine referred to in connection with the auxiliary circuit for the Ignitron generated voltage-peaks displaced in phase by 30 electrical degrees but in synchronism with the a.c. supply, and I am much indebted to Mr. Butler for indicating the possible confusion between the name given to this piece of apparatus and the other well-known type of electrical machine. The rate of evaporation of mercury from the cathode is about $0 \cdot 0008$ cm^3 per sec. per ampere.

The information given about the diffusion of hydrogen bears out similar experiments carried out in connection with the pumpless steel-tank rectifier.

In reply to Prof. Wheatcroft, I regret that complete statistics of installed rectifier equipment were not available owing to lack of accurate data from Continental countries where information about recent installations is not disclosed.

The argument about rotating machinery versus rectifier plant is not entirely dependent upon manual attendance as Prof. Wheatcroft suggests. It may be remarked that efficiency at light load, cheaper building costs, and static operation, all play an important part in determining the selection of rectifier equipment.

The question of glass versus metal for rectifiers is best regarded from the point of view of their relative physical properties. The tensile strength of steel is about 10 times that of glass, and on an elasticity basis the ratio is even more in favour of steel. Another point is the manner in which glass bulbs have to be suspended in cubicles, while steel rectifiers can be fixed rigidly on a base-plate if required. I consider the only way to arrive at a reliable comparison is to compare single units of the glass-bulb and steel-tank types equally loaded. The fact that it has proved possible to build air-cooled steel-tank rectifiers at current outputs in excess of 1 000 amperes leaves no doubt as to the superior properties of the steel construction, and, moreover, taking actual facts into consideration, there is ample evidence that the pumpless rectifier represents the best features of the glass-bulb and the water-cooled types.

With regard to high-tension direct-current transmission, this has already been dealt with in my reply to Mr. Gibson in the Birmingham discussion (see vol. 83, page 468).

Mr. Higgins's general remarks accurately describe the situation, but I would say that 1 000-ampere pumpless units are now being produced and there is no indication that this is going to be an upper limit. With regard to substation capacity, it is interesting to note that a 7 000-kW substation has already been built, using glass-bulb rectifiers, which inclines one to the opinion that as the same output could be obtained with a smaller number of air-cooled steel-tank rectifiers, there is no limit to the substation capacity using the latter type of rectifier for ordinary purposes.

Whether the single-unit arrangement shown on page 453 (vol. 83) of the paper is actually simpler than the air-cooled assembly is open to question when the maintenance of water circuits, relays, vacuum pumps, etc., is taken into consideration.

It is interesting to learn of Mr. Higgins's experience of water-cooled rectifiers; I have also come across many similar examples of low maintenance costs. It may be remarked, however, that had the vitreous-enamel seal been used in the water-cooled rectifier referred to, the anode coolers would not have corroded, as they would have been air-cooled, nor would any rubber gaskets have been required.

The pumpless rectifiers should maintain their vacuum indefinitely and, so far, no seal failures have occurred on site, but test-bed experience indicates that a fault would at once be apparent and not at all difficult to detect.

So far as rotary convertors and rectifiers are concerned, the load factor as well as the full-load efficiency has to be taken into consideration, so that the superior light-load efficiency of the rectifier is often a deciding factor that enables the rectifier to compete successfully with rotating machinery at d.c. voltages as low as 230 volts.

Mr. French's remarks about the jet-wave rectifier are most interesting. I note that he has made a special study of this type of equipment and I should like to thank him for his clear exposition of the process of commutation in such invertors. It occurs to me that the introduction of hydrogen cooling for electrical equipment also removes one of the criticisms that have hitherto been directed against the jet-wave rectifier. The further development of the large units referred to will be awaited with interest.

In reply to Mr. Dundas, the question of the protection of the d.c. side of rectifier equipments depends upon whether the negative rail is earthed or unearthed, the type of load on the system, the nature of the apparatus in parallel with the rectifier, and the general possibility of feed-back under fault conditions. Where the negative is unearthed, the use of a contactor in the negative lead is desirable, while the positive lead should be protected by a circuit-breaker.

For traction work where severe short-circuits are likely, the circuit-breakers should preferably be of the high-speed type.

The desirability of inversion for regenerative braking depends upon two things: first, saving the wear on brake blocks and working down heavy gradients in the case of main-line equipment, and secondly preventing damage to lighting equipment caused by over-voltage generated in trolley-bus systems. With regard to the former problem, the best solution appears to be a rectifier arranged as an invertor across the supply, whilst in the latter case several alternative methods of protection using relays and the like are available.

In reply to Mr. Milner about parallel operation of rectifiers, the additional complication with air-cooled rectifiers is not very great and presents no new features, especially as water-cooled rectifiers of the 12-anode type also require the provision of paralleling arrangements for pairs of anodes when operating from 6-phase rectifier transformers.

DISCUSSION ON "ELECTRIC HEATING FOR MERCHANT SHIPS"*

SCOTTISH CENTRE, AT GLASGOW, 14TH MARCH, 1939

Mr. D. W. Low: A heating load of 1 000 kW on a ship at the present day is taken as a matter of course, and it will not surprise me if this is increased to 2 000 kW in the near future. In 1911 my brother read a paper on "Heating Installation on Passenger Ships" before the Institution of Engineers and Shipbuilders. In that paper electric heating was referred to in a casual manner, as it was thought then that the load required was too large to justify the installation of generators of sufficient capacity to meet the demand. However, as we all know, Diesel engines became popular for the main drive, which altered the technique, and electricity has been widely used for all purposes on board ship, including electric heating, and installations of 500 kW and upwards are quite common even on steam-driven ships. In the past no specification was given as to temperature required, and for steam-heating installations the specification was that the heating surfaces of the radiators were to be 1 sq. ft. for 150 cu. ft. or so of air volume. The Board of Trade, as the author has told us, considers an installation satisfactory if the system will maintain a temperature of 60° F. with an outside temperature of 30° F. Although, as the author remarks, this is not altogether satisfactory, it is something to work upon, and the specification should be elaborated by the owners according to their requirements, which have to be made to suit the passengers and the weather experienced on the route on which the ship sails. In addition to designing installations to meet various weather conditions, in my opinion it is necessary that the system should be flexible and capable of being adjusted to suit the requirements of the various types of passengers who travel at one time, and I think the heating should be controllable by the passengers themselves. In this respect I am not in agreement with the author. In the first place, the installation should have sufficient capacity to meet the worst weather conditions likely to be met on an ordinary voyage. This means that the cables and switches have to be able to carry the maximum load, but, as the author has pointed out, extra generator capacity is not as a rule required specially for the heating load. If the installation has the capacity, it is then necessary to have suitable control for normal conditions. Can the author say whether alternating current has been seriously considered, as its use would undoubtedly simplify the temperature control? If the main drive were electric I understand that the whole electric installation of a ship would be much cheaper. In my experience d.c. thermostats are not altogether satisfactory, unless for very small currents, and it is necessary, of course, to install contactor switches or relay switches to break loads of 500–3 000 watts, and this considerably increases the cost of thermostat control. There are a.c. thermostats on the market which will handle 15 amperes without the use of relays, and these would meet the author's specification given on pages 433 and 434. I should like the author to explain more fully why he considers a thermostat differential of ± 3–4 deg. F. sufficient. I think this would be entirely unsatisfactory, especially if the source of heat were radiant. I think the differential would require to be ± 0·5 deg. F. The range of adjustment should be between 55° F. and 80° F. The thermostats, of course, would require to be of sound construction and fitted with a suitable knob. In the public rooms the thermostat should be under the control of the ship's staff, as it is not possible to suit everybody's requirements. I should like the author to explain Table 4 more fully, and tell us how he arrives at the figures. I think it is quite possible to show greater savings than 20 per cent; and I think also that the savings for the 6 months' period compared with the 3 months' period will be more than double, owing to the average outside temperature for the 6 months' period being higher than for the 3 months. I presume that the three months the author has taken are the three coldest months. I should also like the author to give the cost of the thermostat control on which he based his figures.

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* Paper by Mr. H. CAMDEN MACEWAN (see page 421).

With regard to "Rules and Regulations in respect to Electric Heaters," on page 427, I am inclined to disagree with the author when he says that these rules and regulations are stringent. I think they are very necessary, and I am of opinion that Lloyd's rules are not to be read to mean that the low-temperature radiant heater is debarred. What I think is meant is that heaters of the hot-wire high-temperature type are dangerous, and I agree that this type is not suitable for ships unless suitably guarded. In cases where the losses through the ship's structure are excessive from the economical point of view, radiant-type heaters are preferable, and, for purposes such as the author has shown on a lantern slide, should be of the low-temperature type, the heating surface being as large as possible for the spaces available. However, in the case of crews' quarters I would not go so far as to say that radiant heaters are the best type to install. I think it is necessary to have a certain amount of convection heating. The ideal, I think, is to have a central installation for conditioning the air. This air should be forced through the trunking, and where it enters the cabins it should be heated to a temperature to prevent the "cold draught feeling." In my experience forced air heating is very often unsatisfactory, owing to the fact that the velocity of entry into the cabin is too high. In addition, I would install a heater of the type described on page 430. Possibly one unit in the cabin could be designed to meet this specification. On page 429 the author mentions a case where fire was caused by a chair being placed in front of a recessed-type convector heater. I think the only way to prevent such an occurrence is to fit a thermal fuse inside the heater space. The author goes on to describe an ideal type of electric radiator having the characteristics of a steam radiator that would introduce natural inherent limitation, and he says an element is needed with a temperature/current characteristic such that it will not rise in temperature above a certain degree. He says that that does not seem to be a very impossible thing to demand, certainly not one beyond the skill and ingenuity of the electrical engineer and metallurgist of to-day. I think that all the engineer can put forward to meet these requirements is an electric hot-water radiator controlled by a thermostat which will have the characteristics of the steam radiator.

I suggest that it would have been better to express the heat loss in watts instead of in B.Th.U. per hour in Table 5.

Prof. S. Parker Smith: I am particularly interested in the author's remarks about the steam radiator. Fig. 2 shows that the steam radiator has the great advantage of being to a large extent self-regulating; whereas the electric heater, if not controlled, will go on raising the temperature indefinitely. The author throws out a challenge when he says, "An element is needed with a temperature/current characteristic such that it will not rise in temperature above a certain degree."

In the comparison between radiant and convection heating, it follows that heated air is not what is needed; if the air is hot enough to be useful the place may well become stuffy. I should think the high air temperature would make it easy to catch a chill when passing from the hot stuffy place into the cold air outside. It seems that a strong case for radiant heating has been made out. A combination of air warming and radiant heat would probably enable a fairly economical result to be obtained.

The author gives an interesting reason why radiant heat is better than warmed air, namely that it is only the exposed parts of the body that get the immediate benefit of the warmed air.

I suggest that as we are so accustomed to calculating in terms of kilowatts, it would be useful if these were put alongside the figures for B.Th.U. per hour throughout the paper.

Mr. R. Grange: Speaking as a marine engineer, as a rule my interest in the heating of the ship stops at the engine-room bulkhead, and in that connection I notice on page 426 a passage in which I do not think the author is being quite fair to the waste-heat method of heating air. He says, "In considering waste heat, however, it has to be remembered that it ceases to be available in sufficient quantity when the main propulsion engines are shut down or slowed down to any appreciable extent." That, of course, is only applicable to the motor ship, and the custom of using waste heat in motor ships is to generate steam at 100 lb. per sq. in., whereas I think that if steam were generated at, say 20 lb. per sq. in. additional heat would be available. On the same page the author says "A motor ship, however, may not have steam, and on the high-pressure, high-superheat turbine-driven vessel with high-efficiency boilers, steam suitable for purposes outside the propulsion turbines may not be readily available." I cannot conceive why it should not be available, because all one has to do is to bleed the turbines at some suitable point. I think that the ideal system of heating ships is a combination of radiant electric heating and convection heating through trunks. I can quite confirm what the author says about a convection heater being dangerous, whether in a recess or in an alleyway.

On page 432 the difference between the hot-weather and cold-weather loads is referred to. The author says "As a result of this drop in the load with cooler conditions, extra generator capacity is not as a rule required for electric heating load." I think that is a questionable statement, because in my own experience of electrical loads the heaviest load occurs in a Diesel-engine-driven ship in manœuvring conditions when large air compressors have to be started up. Also there is a time lag when running into cold weather which must be allowed for when slowing down the freezing plant. My experience is that if electric heating is required on board ship a certain amount of extra generator power is necessary.

Prof. C. L. Fortescue: I should like to draw attention to the fact that Fig. 2 is plotted to a false zero and that the zero temperature is at the bottom of the page. The steam radiator is not automatic to the extent that the diagram seems to indicate. It is reducing the power supply from 3 000 to 2 000 B.Th.U. per hour and not to zero.

In a modern ship the heating must be considered in connection with both the cooling and air conditioning. There must necessarily be a very large air circulation, and much of the temperature control will presumably be done on this air. Radiant heating will no doubt assist, but its utility is not entirely a matter of the behaviour of the human body but is in part due to the fact that the objects actually handled are warmed by the same heat which warms the body. That is a point which is not very generally realized, and it makes a difference in the sense that the radiant heat should be applied in such a way that it warms both the occupants of the room and the objects they handle.

Mr. N. C. Bridge: Can the author say what is the annual load factor on the generating plant to which he refers?

Mr. W. J. Cooper: I was most impressed with the statement made in the early part of the paper that the proper way to measure the heat in a room is to measure the loss of heat from the body and not the temperature of the room. The problem appears to resolve itself into a question of air conditioning.

In applying heating to a ship, and so far as cost of electricity is concerned, the only person concerned is the owner of the ship, and whatever it costs him to generate and distribute it, that is what it costs him to use.

Mr. H. C. MacEwan (*in reply*): In reply to Mr. Low's comments upon thermostatic control, I agree that from the point of view of satisfying the few passengers who are very particular it would be better to provide means of adjustment for the passenger himself to manipulate. Unfortunately, however, the mechanism of temperature adjustment in thermostats would not withstand the abuse and rough treatment which is given to ships' equipment, and special thermostats for marine use would be required, with consequent increase in price. Actually such refinements are only used by a very small percentage of the passengers, and from the cost point of view I would prefer to use the standard land equipment with adjusting knobs removed.

In regard to the thermostat differential, the figure of ± 3 or ± 4 deg. F. was arrived at from observation on board ship. The results of research on thermal comfort have established that there is a considerable lag in the sensitivity of the human feelings to changes of temperature, and except where the change of temperature has been very slow indeed it is often quite an appreciable period, half an hour or more, before a person notices that there has been an excessive temperature-drop in a room that has previously been comfortable. Further, observation has indicated that, in general, complaints are not made of a 5 deg. F. temperature drop until after some time, and in view of the fact that the heating on board ship is " on " continuously day and night when in service, it is considered that the thermostat differential should be made as wide as possible, in order to avoid excessive operation of the thermostat, since such excessive operation eventually gives rise to upkeep. Reliability of operation is, on board ship, of greater importance than extreme accuracy of temperature maintenance.

In regard to Table 4, this is given merely to indicate the saving which would be obtained under the circumstances shown. It will be noted that it is based on a total use of 6 months of the year and not on use through a 6 months' period. I have visualized the use of the heating installation over a number of short periods, such as are usually experienced on a ship in service except in, say, the North Atlantic. The basic cost of the thermostat was £2 10s., which is the total cost of a thermostat unit and a contactor to work in conjunction with it. The circumstances which influence and determine the use of heating on board ship are so varied that calculations should be made for each individual case under consideration. I agree with Mr. Low that a greater saving than 20 % is possible. I chose 10 % and 20 % in order to show that even a small saving in units can justify the use of thermostats, and in this, as elsewhere in the paper, I have particularly avoided data which would be in any way exaggerated.

Coming now to the question of alternating current versus direct current, this is too large a subject to cover fully in these comments on electric heating, but as transmission distances on board ship are small and as most of the motors on board ship require speed control, direct current is very much better for ships' installations than alternating current. I appreciate the advantages of alternating current where thermostatic control is used, but the use of contactors and other such switching devices need not be considered a serious disadvantage, since these are now very reliable indeed.

At Prof. Parker Smith's request, I have converted into watts the figures of British thermal units per hour given in Table 1, and the results are set out in Table B.

Mr. Grange considers that I was not quite fair to the use of waste heat for heating on board ship; this is such a very large subject that one hesitates to say anything at all about it, since to be brief might be misleading. It may be pointed out, however, that waste heat can only be converted into something useful by means of some form of conversion equipment, and such equipment is costly. If it were to be used for heating only the amount of use obtained from it could not usually justify the cost, and, in general, it may be said that the product of conversion must be put to some use which will give a fairly constant service of some kind. The best use that could be made of waste heat would be to convert it into electricity, but that presents difficulties. Each case must be judged on its merits, and unless heating is to be in service for an appreciable time throughout the year it will not pay to install waste-heat equipment to supply the heating installation, unless there is some balancing hot-weather service.

In regard to the question of bleeding the turbines at some suitable point, this may be possible on some ships, but in my remark to which Mr. Grange takes exception I had in mind high-efficiency boilers which use distilled water.

Mr. Grange also questions the statement on page 432 in regard to the necessity of extra generator capacity, but it should be noted that in that paragraph I am speaking of ships with electrical systems large enough to have a hot-weather load. The statement is not a generalization. Where no such drop in the load occurs to cancel out the heating load, obviously a heating peak will occur in the load curve, and, as is pointed out in the early paragraphs of the paper, additional generator capacity for heating alone would usually make the cost of electric heating prohibitive. The whole question is a matter which has to be decided in the early stages of design. The loads which will occur at various periods of the ship's voyage are closely estimated, and the necessity for extra generator capacity for heating alone will show itself then.

most prolonged running of the compressors, which is usually the ruling factor in providing for the compressor load. Mr. Grange will appreciate that gradually but surely chief engineers and electricians are becoming more and more alive to the fact that a very great deal can be done on the main switchboard by easing down pumps, fans, refrigeration, and similar loads, when the compressor load peak is of short duration.

Table B

Surface	Heat-loss coefficients in watts per sq. ft. per deg. F. difference under conditions as follows:—		
	Mild conditions	Full exposure to average winter wind and weather (say not more than 5 deg. to 10 deg. F. of frost)	Exposed to severe cold and weather as North Atlantic and Baltic
Steel			
Painted only or covered with thin cork-dust and paint	0·29 to 0·53	0·59	0·73
Lined bulkhead, i.e. steel, with blocked air-space of 2–4 in. and $\frac{3}{8}$–$\frac{1}{2}$ in. wood or composition board panelling ..	0·15	0·16	0·17
Public room, panelled bulkheads	0·12	0·13	0·14
Deck overhead with 3 in. wood deck planking to weather	0·13	0·15	0·15
Wood Partitions			
$\frac{7}{8}$ in. plywood bulkhead	0·13	—	—
Single-panel bulkhead	0·15	0·17	0·18
Double hollow teak or composition board bulkhead ..	0·1	0·11	0·12
Wood Doors			
Teak outside door	0·11	0·12	0·13
Whitewood inside door	0·13	—	—
Vestibule double doors	0·07	0·08	0·09
Plaster Work in public rooms, lining steel	0·12	0·13	0·14
Glass			
Portholes with brass frames	0·32	0·35	0·37
Public room, large windows to promenade deck ..	0·3	0·34	0·35
Public room, dummy windows without wood lining ..	0·29	0·32	0·34
Public room, dummy windows with bulkhead lined ..	0·18	0·19	0·2
Deck (*Floor*) *Steel below*			
$2\frac{1}{2}$ in. wood planking	0·1	0·11	0·12
1 in. composition decking	0·13	—	—
Cork slabs	0·08	—	—

It might, in fact, pay sometimes to accept a heating peak. That depends on the percentage of extra generator capacity required and the extra cost that that extra capacity will give rise to on the particular size of generators. It also depends on the cost of heating with other systems. In the case of large ships, however, with a hot-weather load, I have never seen a heating peak on the records of loads.

In regard to the air-compressor load in manœuvring conditions, this does not affect the question, for that load has to be met in hot weather as well as in cold weather, and indeed some of the hot-weather ports give rise to the

In reply to Mr. Bridge, I regret that I am unable to give annual load factors on ships' generator plant. They depend very largely upon the type of vessel, and to some extent upon its trade. Further, it is only very occasionally that units are measured on ships. As an indication, however, it may be said that the diversity factors, representing the actual loads as a percentage of the connected loads of equipment in service at the times given below, are usually approximately as follows on marine electrical installations of appreciable size: Maximum load at sea, 0·45 to 0·7; maximum load in port, 0·33; maximum load coming into port, 0·3.

DISCUSSION ON

"THE SURGE PROTECTION OF POWER TRANSFORMERS"*

NORTH MIDLAND CENTRE, AT LEEDS, 22ND NOVEMBER, 1938

Mr. F. Gurney: Some 2–3 years ago Mr. Johnstone Wright said that over a period of 5 years the proportion of C.E.B. breakdowns on transformers attributable to lightning was less than 1 %. There does not seem to be any information available regarding transformer failures due to lightning at the lower voltages of 33 kV and 11 kV, but the trouble is not a prevalent one. Transformers connected to overhead lines are subjected to transients having high voltage amplitudes and high time rates of voltage-change, but the work done by various investigators using the cathode-ray oscillograph has resulted in a radical improvement in the design of transformers, and most modern transformers are unaffected by these transients.

I should like to ask whether equivalent protection to that given by the authors' surge absorbers could not be obtained by correct internal design of the transformer. A further question arises out of this: where surge absorbers are used before a transformer, would the authors consider that the transformer need be of normal design only, without special precautions against damage to insulation by transients?

I should be glad to learn of any practical experience which the authors may have as to the effect of the surge absorber in practice. They do not appear to claim that it prevents lightning outages, or subscribes materially to the protection of the other parts of the overhead-line system. Given, therefore, transformers that are designed to be reasonably immune from transients, I consider that a scheme of lightning arresters might provide a more general safeguard to the whole system, and I suggest that the total cost of a lightning-arrester scheme might be lower than that of the complete protection of all transformers by surge absorbers.

I think it is agreed that earth-wire protection is the best protection for an overhead-line system against lightning. As a safeguard against direct strokes, is the surge absorber a satisfactory substitute for adequate overhead earthing?

I gathered from the authors' remarks that the surge absorber has to be capable of withstanding very high voltages, and I should like to know what routine tests are made to determine its capabilities in this respect.

Mr. Douglas C. Field: The paper contains a great deal of useful information on the behaviour of surge absorbers, and it would have been interesting to have had comparative details of the behaviour of lightning arresters under similar circumstances.

From the description given by the author of the effect of travelling and chopped waves when condensers, inductances, and surge absorbers are used, it would appear that a combination of an arrester with a surge absorber (or even an inductance) would provide very effective protection.

I agree as to the importance of having low earth resistances, but I think the author over-estimates the difficulty of providing these at substations; apart from exceptional conditions, and in the case of small pole equipments, it should be possible to get down to a figure of 1 ohm, which, with a surge current of as much as 100 000 amperes, would still keep the voltage down to a reasonably low figure.

It would be of interest to have fuller particulars of the reinforcement to the inter-turn insulation of the transformers tested. It would appear from the results that the first 10 % of the windings was reinforced, and presumably the insulation was graded.

The authors' diagrams show that the maximum gradients usually occur from 10 % to 30 % from the end of the winding, and in my experience it is in this region that the majority of breakdowns occur. The results suggest that the usual practice with regard to end-turn reinforcement should be modified and additional insulation be carried down to 30 % from the end of the winding.

Although knowledge of the voltage gradient in the insulation is a necessary first step, what we are really concerned with is the possibility of breakdown. The voltage gradient increases with the steepness of the wave, but so also—as the author mentions in the case of insulators—would the impulse ratio of the insulation increase. A correction for this is necessary before a true comparison of the severity of conditions can be made.

Mr. B. D. Youatt: The authors call attention to the necessity for flashover to take place on the line side rather than the transformer side of the absorber. Does not this involve graded insulation levels and thus co-ordinating gaps, to attempt to overcome the well-known surge instability under varying weather conditions of exposed line and bushing insulators? If so, it is difficult to reconcile this with the authors' very pertinent remarks on the behaviour of gaps under impulse voltage, and on the necessity for low settings to catch the steep-fronted wave, with consequent increased number of flashovers on the slower waves.

When demonstrating the effect of condensers used as wave-flatteners, capacitances of 6 000 $\mu\mu$F and 1 700 $\mu\mu$F were used. The larger capacitance showed results comparable with those given by the absorber in flattening travelling waves. The capacitance of a 20-yard terminal length of cable with $0\cdot 5$ μF capacitance per mile is of the order 6 000 $\mu\mu$F. Will the authors agree that the beneficent, if limited, effects of a condenser are obtained by such terminal lengths, and, since their test results also show further improvement with greater capacitance, that longer terminal lengths give still better protection?

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* Paper by Drs. J. L. Miller and J. M. Thomson (see page 187).

Mr. J. E. L. Robinson: In the past, transformers have been variously regarded as prone to failure under lightning conditions in the axial or in the major insulation. In the paper the authors present a weight of evidence demonstrating the axial vulnerability. As was shown in the London discussion (see page 217), for a transformer designed in accordance with British Standard Specifications under the worst travelling-wave conditions the major insulation has a safety factor of the order of 2·1 or more, while the axial insulation is likely to have a factor of weakness of some 0·7. That is, under travelling-wave conditions the axial strength is about one-third of the major strength; under flashover conditions the disparity is considerably greater.

It is shown in the paper how the surge absorber effectively reduces the axial stresses to one-third under travelling-wave conditions, and to less than this under flashover conditions. In this way the surge absorber effectively removes the existing disparity between the axial and major insulation-strengths. Additionally, however, as I have shown in the Manchester discussion (see page 225), the surge absorber limits the amplitude of the surge voltage on the transformer irrespective of the severity of the lightning conditions to the maximum possible travelling-wave voltage, under which condition, as has already been demonstrated, the major insulation has a factor of safety of some 2·1. It is similarly demonstrated in my contribution to the Manchester discussion that the surge absorber under any conditions probably also imposes a limit to the axial stresses, and that in this way a normal transformer winding is afforded complete protection.

Mr. R. M. Longman: On the grid system in this area only one breakdown of a transformer due to lightning has occurred, and in this case there was a heavy lightning discharge in the vicinity of a short overhead line connected directly to the transformer terminals. In South Lincolnshire the Board have 200 miles of overhead 33-kV lines, with 20 transformers connected, but in all cases there are lengths of cable between the lines and the transformers, and although a number of flashovers have occurred on the lines due to lightning no transformer failures have occurred. Possibly the cables have had some beneficial effect. In one case surge absorbers were installed on one transformer and omitted on the second unit, but neither transformer has suffered.

There appears to be a good case for installing surge absorbers on pole-type transformers or transformers directly connected to overhead lines, in those districts which are subject to lightning. The results obtained are so often of a negative character.

On all the Board's lines there is an earth wire above the conductors. I suggest that the reinforcement of the end turns of transformer windings should extend to 30 % of the windings; this might obviate the use of surge absorbers. Co-ordinating gaps are provided on one transformer of each pair on the lower-voltage sides (operating at 33 kV). Whilst these have flashed-over on occasion, tripping the units out, none of the transformers has been affected.

Dr. J. L. Miller and **Dr. J. M. Thomson** (*in reply*): Mr. Gurney refers to the fact that 1 % of transformers on the C.E.B. system are broken-down by lightning, and deduces therefrom that, as far as transformer damage attributable to this cause is concerned, the trouble is not a prevalent one. Nevertheless, it ought to be clear that a large organization spread over the whole country and operating large numbers of transformers, many of which are not in lightning areas and none of which are in severe lightning areas, is bound to show a small overall percentage of breakdowns. Despite this, however, perusal of the C.E.B. annual reports will show that their engineers still consider the problem of sufficient importance to warrant the sponsoring of considerable research on lightning protective devices, both financially and otherwise. Further, in other countries, where lightning is much more prevalent than in ours, operating engineers are continually purchasing lightning protective devices for transformers—from our own firm and many others—and surely this indicates that in those countries considerable trouble is experienced; we should not very well be able to sell devices for which there was no demand. We do not agree, therefore, with the general attitude expressed by Mr. Gurney in his first paragraph, nor do we subscribe to the view that a modern normal transformer is unaffected by transients, although we would go so far as to state that recent knowledge has resulted in designs which will enable windings to withstand more punishment than has been the case hitherto. These views are expanded somewhat in the next paragraph, in which we reply to Mr. Gurney's second paragraph.

So far as travelling waves and chopped conditions are concerned, no doubt protection equivalent to that given by the surge absorber can be built into the transformer. This point is referred to in Sections (2)(*g*), (3)(*a*), and (3)(*b*) of the paper. Nevertheless, such protection cannot be obtained without an increase in cost. Surge protection, whether obtained inherently in the transformer or by the use of surge absorbers or other devices, costs money, like any other form of insurance. So far as direct strokes or nearby strokes are concerned, however, the problem is somewhat different. The surge absorber, to use Mr. Robinson's words ". . . limits the amplitude of the surge voltage on the transformer irrespective of the severity of the lightning conditions to the maximum possible travelling-wave voltage. . . ." The transformer is thus safe. To obtain the same protection against direct strokes, where, it will be remembered, the surge voltage may rise to a figure of 3 to 5 times the maximum travelling-wave voltage, by designing the winding of a transformer so that both its axial and its major insulation will inherently withstand such voltages, leads to a large and expensive design.

Lightning arresters could not safeguard the whole system, of course, unless large numbers were distributed along the lines. They are normally used to hold the voltage down at the substation.

Our reply to Dr. Allibone in the London discussion covers the question of tests on surge absorbers, and our other remarks there and in Manchester refer to the other question of direct-stroke protection raised by Mr. Gurney.

Mr. Gurney would also be glad to learn of any practical experience which we may have as to the effect of the surge absorber in practice. This is a point which has been touched upon in one form or another by many contributors to the three discussions. Since we are not operating engineers ourselves, the only reply we can make is to quote a typical extract from the numerous reports which reach us from operating engineers. A Canadian supply undertaking, after 4 years' operating experience on a large scale, states "Since the installation of surge absorbers there has been continuous service and no ill effects from lightning. It may be stated that before the installation of surge absorbers on our system we lost on an average 2–4 transformers each year from the effect of lightning." The instance given is representative of a very large number.

Mr. Field says it would have been interesting to have had comparative details of the behaviour of lightning arresters. In reply, we will quote one other typical operating report, from a large rural system with over 2 years' experience of surge absorbers. The engineer states "Our experience with surge-proof transformers (i.e. a transformer with surge absorbers in the terminal pockets) has been gratifying and much more satisfactory than with the ordinary transformer having separate arresters. . . ."

We agree that a surge absorber in combination with an arrester would be a very satisfactory combination, but owing to the voltage-limiting properties of the surge absorber a plain gap across its line terminal is just as satisfactory; further, if an expulsion-type gap is used, circuit-breaker operation after a surge flashover will generally be prevented. Referring to the earth-resistance question, we agree that to obtain low values of the resistance is generally practicable at large substations, particularly in this country. The difficulties we had in mind referred to the smaller isolated substations, particularly in foreign countries, where values as high as 100 to 500 ohms are common.

On the normal transformers described in the paper, the first 4 % or 5 % of the turns of the winding were reinforced, i.e. the usual amount. The figure of approximately 10 % which is evident from the distribution curves appears because for several reasons we preferred to count by sections rather than by turns.

We are glad to have confirmation from Mr. Field that in his experience surge breakdowns occur in the 10 %–30 % region of the winding. As we pointed out to Mr. Gibson in the London discussion, this is also our experience. The results certainly suggest that the usual practice with regard to end-turn reinforcement should be modified, and, as both Mr. Field and Mr. Longman point out, there is a very good case for extending it down to 30 % of the winding.

Mr. Youatt raises a very pertinent question. In arranging for the inevitable flashover under the severer conditions to take place on the line side of the absorber, one is only concerned that the voltage remaining at this point after flashover is of reasonably short duration. Then, even if the gap or bushing has a large setting (so that ordinary travelling waves do not operate it) and a large impulse ratio, so that the large voltage on the line at this point has a large amplitude, the relatively brief duration of this voltage in combination with the characteristics of the surge absorber will ensure that only a voltage of much smaller amplitude will appear at the transformer terminal. All the distribution curves in Section (5)(*e*) of the paper take this fact into account; as is stated, impulse ratios from 2 to 5 have been variously assumed there, depending on the conditions.

When dealing with the question, raised by Mr. Youatt, of cables versus condensers as a surge protective device, it must be remembered that at the equivalent frequencies with which we are concerned in lightning problems the condenser has concentrated constants while the cable has distributed ones. Thus a cable as short as 20 yd. will, according to the usual laws, pass on to the transformer a stepped wave-front, each step being almost as steep as the front of the original voltage on the line.* On the other hand, a condenser gives a smooth rounded front; so that a condenser and a cable, both having the same capacitance, do not give the same kind of protection. The stepped front issuing from the cable, in our experience, makes its protection of less value, as far as the axial stresses are concerned, than that of the condenser, and, in addition, it has, of course, the other drawbacks of the condenser. If the cable is longer, attenuation in the cable will round off the steps, but no voltage-amplitude reduction over and above that occurring with the equivalent condensers will result. It is only when the cable is really long that its protective value becomes better than that of the condenser of equal capacitance.

We are very interested to have Mr. Longman's remarks. It would have been valuable if he had given the lengths of the cables involved, and the distance out along the line where the flashovers he mentions occurred. The cables were quite possibly having considerably beneficial effects —as we have pointed out to Mr. Youatt, their protective value depends on their length.

As Mr. Longman states, there is a very good case for surge-absorber installation on pole-type transformers. Actually, as we said in the previous discussions, 90 % of the surge absorbers now manufactured in Canada are mounted in the terminal pockets of pole-type transformers, and 50 % of our distribution transformers are so equipped.

Mr. Longman's remarks about gaps on the lower-voltage sides of transformers are interesting. Before one can give an opinion it is necessary, of course, to know their settings—the question is touched upon in Section (2)(*f*) of the paper.

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* J. L. Miller: "Surges in Transmission Lines and Transformers," *Engineering*, 1935, vol. 140, pp. 429 and 461.
The steps will only be prominent if the wave-front duration is less than twice the time of propagation in the cable.

PROCEEDINGS OF THE INSTITUTION

935TH ORDINARY MEETING, 3RD NOVEMBER, 1938

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 20th October, 1938, were taken as read and were confirmed and signed.

The President announced that during the month of October 114 donations and subscriptions to the Benevolent Fund had been received, amounting to £813. A vote of thanks was accorded to the donors.

Messrs. H. W. Grimmitt and F. Small were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, it was reported that the members whose names appeared on the lists (see page 157) had been duly elected and transferred.

A paper by Dr. T. E. Allibone, Ph.D., Associate Member, entitled " The Mechanism of the Long Spark " (see vol. 82, page 513), was read and discussed (see vol. 84, page 483). The paper was accompanied by a demonstration of apparatus.

A vote of thanks to the author, moved by the President, was carried with acclamation.

936TH ORDINARY MEETING, 10TH NOVEMBER, 1938

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 3rd November, 1938, were taken as read and were confirmed and signed.

A paper by Mr. H. S. Hvistendahl, B.Sc.(Eng.), Associate Member, entitled " Thermal Power Plants for Peak-Load and Emergency Service " (see page 305), was read and discussed.

A vote of thanks to the author, moved by the President, was carried with acclamation.

937TH ORDINARY MEETING, 24TH NOVEMBER, 1938

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 10th November, 1938, were taken as read and were confirmed and signed.

A paper by Mr. H. Camden MacEwan, Associate Member, entitled " Electric Heating for Merchant Ships " (see page 421), was read and discussed.

A vote of thanks to the author, moved by the President, was carried with acclamation.

938TH ORDINARY MEETING, 1ST DECEMBER, 1938

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 24th November, 1938, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

A paper by Mr. R. Nelson, Member, entitled " Electricity in Coal Mines: a Retrospect and a Forecast " (see page 597), was read and discussed.

A vote of thanks to the author, moved by the President, was carried with acclamation.

939TH ORDINARY MEETING, 15TH DECEMBER, 1938

Dr. A. P. M. Fleming, C.B.E., M.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 1st December, 1938, were taken as read and were confirmed and signed.

The President announced that during the month of November 52 donations and subscriptions to the Benevolent Fund had been received, amounting to £177. A vote of thanks was accorded to the donors.

A paper by Mr. K. L. Wood, Member, entitled " Empire Telegraph Communications " (see page 638), was read and discussed.

Between 6.20 p.m. and 6.25 p.m. communication was established with Cape Town on a wireless automatic printing circuit, the following message being received by the President from Mr. G. H. Swingler, Local Honorary Secretary for the Cape, Natal, and Rhodesia:—

> " Members in South Africa realizing that dependable and rapid means of Empire communication have been essential to the building up of the British Commonwealth of Nations are glad to have an opportunity of sending their greetings and best wishes during the reading of this important paper."

To this the President sent the following reply:—

> "Warmest thanks for message. Heartily reciprocate good wishes from South Africa."

Subsequently between 6.45 and 7 p.m. a demonstration took place of printing on a cable circuit established between The Institution and Singapore and back, via Penang, Colombo, Seychelles, Aden, Port Sudan, Suez, Alexandria, Malta, and Gibraltar. In the course of this demonstration the following messages were received:—

> "The Chairman and members Ceylon Local Committee I.E.E. send greetings to President and members Institution assembled in London."
>
> "The President and members of the Engineering Association of Malaya are pleased to take this opportunity of conveying heartiest greetings to the President, members, and visitors of The Institution of Electrical Engineers."

In reply to these the President sent the following messages respectively:—

> "Warmest thanks for message. Heartily reciprocate good wishes from Ceylon."
>
> "Warmest thanks for message. Heartily reciprocate good wishes from Malaya."

At the conclusion of the discussion a vote of thanks to the author, moved by the President, was carried with acclamation.

INSTITUTION NOTES

THE SECRETARY

The Council have appointed Mr. W. K. Brasher, B.A., Member, to succeed Mr. P. F. Rowell as Secretary of The Institution.

Mr. Brasher, who will take up his duties on the 1st September, was educated at Clifton College and at St. John's College, Cambridge. During the War he held a commission in the Royal Engineers (Signals) and served in France. Subsequently, after eight years in the Post Office Engineering Department of British Guiana and four years in the Department of Posts and Telegraphs, Iraq, he was appointed in April, 1933, to his present position of Chief Engineer, Posts and Telegraphs, Palestine.

LIBRARY

The Council have decided to afford facilities up to 8 p.m. on any evening during the summer (Mondays to Fridays inclusive) to members who wish to use the Institution Library after office hours. Any member desiring to be given access to the Library between 5.30 p.m. and 8 p.m. must notify the Secretary beforehand by letter, or by telephone not later than midday on the day concerned, so that the necessary arrangements can be made.

MILITARY TRAINING ACT

Consideration has been given by the War Office to a suggestion that steps be taken to ensure that Students of the leading engineering and professional Institutions when called up to carry out their six months' training as militiamen, are posted to Units in which their service would be most valuable and, at the same time, where the training would be of use to them in their civilian work. As a result, arrangements have been made by the authorities concerned for special instructions to be given to "interviewing" officers that a note should be taken of anyone called up being a member of any such Institution, so that "posting" officers will know how his services can best be utilized.

I.E.E. Students should therefore specifically mention their membership when supplying particulars of their qualifications to the "interviewing" officers, and should indicate their desire to join one of the technical Units, such as the Royal Corps of Signals, the Royal Engineers, and the Air Defence Great Britain (Searchlights).

INDEX TO JOURNAL

Any member who proposes to bind the current volume of the *Journal* and would like to have an extra copy of the Index for filing apart from the bound volume of the *Journal* can obtain an additional copy on application to the Secretary.

"SCIENCE REVIEW"

The British Broadcasting Corporation have asked that the attention of members be drawn to a programme of topical science which is broadcast every fortnight under the title of "Science Review." Each programme is of about 18 minutes' duration, and the aim is to provide listeners with first-hand information about current events in the world of science that are likely to be of interest to a relatively wide audience with no scientific training but with a predisposition to listen to such material.

The B.B.C. will be pleased to receive suggestions as to material and speakers for the talks. Suggestions should be sent to the Director of Talks, The British Broadcasting Corporation, Broadcasting House, London, W.1.

PREMIUMS

At the Annual General Meeting held on the 11th May, the President announced that the Council had made the following awards of Premiums for papers during the session 1938–39:—

The Institution Premium (*value* £25).

T. E. Allibone, D.Sc., Ph.D., F. E. Bancroft, and G. S. Innes, B.Sc.	"The St. Bartholomew's Hospital X-Ray Tube for One Million Volts."

The Ayrton Premium (*value* £10).

F. W. Lawton	"The Design and Operation of Hams Hall Power Station."

The Fahie Premium (*value* £10).

K. L. Wood	"Empire Telegraph Communications."

The John Hopkinson Premium (*value* £10).

N. F. T. Saunders, B.Sc.	"The Design of Fractional Horsepower Induction Motors."

The Kelvin Premium (*value* £10).

L. Hartshorn, D.Sc., and E. Rushton, B.Sc.	"The Dielectric Properties of Cellulose Acetate" (E.R.A. Report).

The Paris Exhibition (1881) *Premium* (*value* £10).

R. Nelson	"Electricity in Coal-Mines: a Retrospect and a Forecast."

The Webber Premium (*value* £10).

N. F. S. Hecht	"Radio in Aviation: A General Survey, with special reference to the Royal Air Force."

An Overseas Premium (*value* £10).

H. S. Hvistendahl, B.Sc.(Eng.)	"Thermal Power Plants for Peak-Load and Emergency Service."

A Premium (*value* £10).

G. H. Fletcher and A. Tustin, M.Sc.	"The Metadyne, and its Application to Electric Traction."

A Premium (*value* £5).

W. Betteridge, B.Sc., Ph.D., and J. A. Laird	"The Wear of Electrical Contact Points."

A Premium (*value* £5).

F. Brailsford, Wh.Sc., B.Sc.(Eng.)	"Alternating Hysteresis Loss in Electrical Sheet Steels." "Rotational Hysteresis Loss in Electrical Sheet Steels."

A Premium (*value* £5).

J. Higham, M.Sc., and J. P. Wolfenden, M.Sc.	"Voltage Regulation of the Six-Phase Fork-Connected, Grid-Controlled, Mercury-Arc Rectifier."

A Premium (*value* £5).

K. L. Jensen, Ph.D., B.Sc.(Eng.)	"The Design of a Polarized Telegraph Relay."

Wireless Section Premiums

Duddell Premium (*value* £20).

L. W. Hayes and B. N. MacLarty, O.B.E.	"The Empire Service Broadcasting Station at Daventry."

A Premium (*value* £10).

J. D. McGee, M.Sc., Ph.D., and H. G. Lubszynski, Dr.Ing.	"E.M.I. Cathode-Ray Television Transmission Tubes."

A Premium (*value* £10).

R. L. Smith-Rose, D.Sc., Ph.D., and H. G. Hopkins, B.Sc., Ph.D.	"Radio Direction-Finding on Wavelengths between 6 and 10 Metres (Frequencies 50 to 30 Mc./sec.)."

A Premium (*value* £5).

P. R. Coursey, B.Sc. (Eng.), and S. N. Ray, M.Sc., B.Sc. (Eng.)	"Electrolytic Condensers."

Meter and Instrument Section Premiums

The Silvanus Thompson Premium (*value* £20).

E. G. James, B.Sc., Ph.D., G. R. Polgreen, B.Sc., and G. W. Warren, B.Sc.	"Instruments incorporating Thermionic Valves, and their Characteristics."

A Premium (*value* £10).

H. M. Barlow, Ph.D.	"The Electrical Protection of Cold-Cathode Luminous Discharge-Tube Installations."

A Premium (*value* £5).

D. C. Gall	"A Review of the Design and Use of Potentiometers."

A Premium (*value* £5).

G. F. Shotter	"A Critical Survey of American Metering Practice."

Transmission Section Premiums

The Sebastian de Ferranti Premium (*value* £20).

W. G. Radley, Ph.D. (Eng.), and C. E. Richards	"The Corrosion of Underground Cables."

A Premium (*value* £10).

Prof. W. J. John, B.Sc. (Eng.), and C. H. W. Clark, Ph.D.	"Testing of Transmission-Line Insulators under Deposit Conditions."

A Premium (*value* £5).

E. W. W. Double, B.Sc., and W. D. Tuck, B.Sc.	"Vibration of Overhead-Line Conductors."

A Premium (*value* £5).

T. R. Scott, B.Sc., and R. C. Mildner, M.Sc.(Eng.) "Long-Period Ageing Tests on Solid-Type Cable."

The awards for papers read before the Students' Sections will be published later.

COUNCIL'S NOMINATIONS FOR ELECTION TO THE COUNCIL

The following have been nominated by the Council for the vacancies which will occur in the offices of President, Vice-President, Honorary Treasurer, and Ordinary Members of Council, on the 30th September, 1939:—

President. (*One Vacancy.*)

Johnstone Wright

Vice-President. (*One Vacancy.*)

Colonel A. S. Angwin, D.S.O., M.C.

Honorary Treasurer. (*One Vacancy.*)

W. McClelland, C.B., O.B.E.

Ordinary Members of Council.

Members. (*Six Vacancies.*)

E. S. Byng
H. J. Cash
P. Good
Prof. W. J. John, B.Sc.(Eng.)
A. L. Lunn
H. W. Swann

Associate Member. (*One Vacancy.*)

Professor Willis Jackson, D.Sc., D.Phil.

Associate. (*One Vacancy.*)

D. Z. de Ferranti

ELECTIONS AND TRANSFERS

At the Ordinary Meeting of The Institution held on the 13th April, 1939, the following elections and transfers were effected:—

Elections

Member

van Staveren, Jakob Cornelis, Prof.

Associate Members

Babb, Dudley Austen, Lieut. Commander, R.N. (Ret.).
Bright, Harold, M.A.
Curzon, Thomas, B.Sc. Tech.
Pearce, Harry Felix, B.A.
Storm, Alfred Geberhard.

Companion

Holroyde, Eustace Cunliffe.

Associates

Bompas, George Gwinnett.
Mackie, Edwin George.
Meeks, Cecil Alfred L.
Ovenden, Charles William.
Stewart, Thomas.
Willis, William.

Graduates

Apps, Arthur Frederick.
Carr, Geoffrey, B.Sc.
Chicken, Wilfrid James, B.Sc.
Clarke, Thomas George.
Collins, Lucas, B.E., B.Sc.
Crouchley, Harry Lucas, B.Sc.Tech.
Datta, Saroj, Ph.D.
Dimant, Zygmunt.

Graduates—continued.

Dowling, Kevin, B.E.
Erroll, Frederick James, B.A.
Gillitt, Edward James.
Graham, George Edward G., B.Sc.
Haldar, Bibhat Ranjan.
Hodgkiss, James Wilson, M.Sc.Tech.
Holden, John Alan.
James, John Frederick, B.Sc.
Jones, Frederick, B.Sc.
Parks, George Henry, B.Sc.
Ritson, Frederick James U.
Small, George Robert.
Stevens, Francis Geoffry.
Townsend, Ralph.
Walsh, Alan, B.Sc.
Warrington, Rubert Anthony.
Winton, Robert Charles, B.Sc.

Students

Adam, George Morrison.
Ali, Syed Rauf.
Anajpure, Sadashiv Raghunath.
Ananthanarayanan, M. R.
Atkinson, James.
Bailey, William.
Bainbridge, Thomas Roy.
Bainbridge, William Chapman.
Banerjee, Shib Das.
Baxter, William Henry.
Bendre, Shardchandra Shivram.
Bhaskare, Manhuker Balwant.
Bishop, John Norman.
Blackburn, Arthur Ryland.
Branch, Burton George.
Breitenbach, Hans Wolf.
Brettell, Bernard John.
Browne, Kenneth Francis K.
Bumby, Frank Kenneth.
Cairnduff, William Patrick.
Caldwell, Norman Denew.
Chatterjee, Sudhir Kumar.
Chiranjeevirao, Athmakur.
Clark, Robert.
Clarke, Norman Marland.
Cockburn, Andrew Stoddart.
Cockrill, Alexander Ross.
Collard, James Glover.
Coop, John.
Crawford, Leonard Early.
Croxton, John Gwilt.
Cutting, Peter Leslie.
Dakshinamurthy, K.
Dalvi, Chandrakant Ramkrishna.
Dempster, George Wilson.
Denton, Eric Douglas.
Dey, Sukumar.
Dey, Sunil Kumar.
de Zoysa, Eustace Walter.
Dummer, David Maurice.
Earp, William Adams.
Elijah, Percy Nathan.
El-Shinnawi, Mamoun Mamoun.
Espir, John Robert F.
Galloway, Ian Robertson.
Galloway, James John.
Gibson, Robert Sleigh.
Gittus, Henry William.
Grayston, Robert Edward.
Griffiths, Francis.
Harris, Albert.
Hartland, Cyril Clifford.
Hayton, Thomas.
Heard, John Bennett.
Heathcote, Leonard Henry.
Hickmott, Ian Edwin.
Inman, John Douglas.
Jennings, Douglas Richard.
Kamat, Gopinath Shantaram.
Keeling, Julian Philip J., B.Sc.(Eng.).
Khan, Mohammad Akram.
Krishna, Srinivas Muthu.
Kulashreshtha, Govind Swarup.
Langton, Edward John.
Le Sueur, Claude Michael de V.
Lewis, Mansel.
Lima, Louis Francis.
Livingstone, Harold.
Lowe, Alexander James.
Lund, Wilfred.
McAllister, Douglas Hay.
Maddock, Wilfred Stanley.
Mannering, Montague Herbert.
Marlow, Jack.
Marsh, Ronald.
Milson, Alexander.
Mittra, Amalendu Kumar.
Moody, Philip Harry.
Morgenstern, Curt Peter.
Morris, Richard Arthur.
Morrish, Reginald William.
Murch, Derrick Clifford.
Nagarkatti, Anand Shripad.

Students—continued.

Nickolls, Charles Vale.
Nicoll, John Henry.
Nield, Philip Newton.
Nuttall, Geoffrey Harold.
Overton, Charles George W.
Panchal, Narbheram Purushottam.
Paramu, S.
Pathak, Bapalal Gaurishanker.
Peake, Laurence Russell.
Periyaswamy, K.
Pim, John Albert.
Pollock, Eric James.
Potier, Michael Ernest.
Powell, George.
Quincey, Kenneth Harry.
Radcliffe, Raymond Richard C.
Raina, Priem Nath.
Rao, Mandalika Virabhadra.
Redman, Geoffrey.
Richardson, Arthur Cyril R.
Robertson, Archibald Colin C.
Robertson, Donald.
Ross, Kenneth Wilson.
Rowse, Ernest Victor.
Sadiq, Syed Abdul.
Samsi, Ramesh Vithal.
Satagopam, P. R.
Satpute, Janardan Vyankatesh.
Scott, Joyce William.
Seervai, Fredun Piroshaw.
SenGupta, Santosh Kumar.
Shah, Gopaldas Chhotalal.
Shah, Navnitlal Popatlal.
Shroff, Adi Kaikhusroo.
Shroff, Eric Rustomji.
Shukla, Shankar Bapuji.
Sikdar, Ranjit Kumar.
Simons, Michael Edward G.
Singh, Bansh Raj.
Singh, Harbans.
Singh, Pritam.
Singhal, Om Prakash.
Spinner, John Vigor.
Srinivasan, G.
Stanley, John Gordon H.
Sykes, William Harold.
Szkolny, Geore Franz.
Tarplett, Kenneth Irving.
Tewari, Pran Nath M.
Thatcher, Leslie John.
Tidder, Arthur Reginald.
Turner, Robert William S.
Vaidyanathan, K. R.
Venkatarao, Gollakota.
Venkatesan, Sundaramaiyer.
Vyas, Rasiklal Bhagvanlal.
Waite, Thomas Castles.
Walker, Melbourne.
Walker, Reginald George.
Ward, Cecil Betley C.
Ward, Malcolm Russell.
Wilkins, Eric Lionel.
Williams, Thomas.
Willis, Jack.
Wilson, Michael.
Wood, William Henry.

Transfers

Associate Member to Member

Ahmed, Abdel Aziz, D.Sc., Ph.D.(Eng.).
Alger, Thomas Edwin.
Brierley, Herbert.
Brown, Walter John, B.Sc.
Edwards, Frank Stanley, B.Sc.
Elphick, Eric de Bock.
Francis, Thomas George, B.Sc.
Jeffrey, Leonard Frank, B.Sc.(Eng.).
Sclar, Isaac.
West, Harry.

Associate to Associate Member

Ayres, Talbot Martin.
James, Ivor Robert.
Williams, Alfred Thomas.

Graduate to Associate Member

Baker, Ernest Roy, B.Sc. (Eng.).
Billcliff, Jack.
Bowring, Frederick Alfred.
Brooke, Anthony John.
Burke, Anthony, B.E.
Burrows, Thomas Kenneth.
Cutland, George.
Dunford, Arthur, B.A.
Dyson-Laurie, Waulter de Molesworth, M.A.
Edwards, Richard Grosvenor, B.Sc.(Eng.).
Fitzer, Herbert Clyde, B.Sc.(Eng.).
Green, Sam.

Graduate to Associate Member—continued.

Guild, Joseph Buick.
Hamilton, Robert Nelson, B.Sc.(Eng.).
Holland, Charles John A.
Holloway, Arthur Gordon P., B.Sc.(Eng.).
Hopewell, Cecil John.
Innes, George Smith, B.Sc.
Jackson, Gilbert.
Koshairy, Mohammed Abdel B. El, B.Sc.
Lambrick, George Menzies T., Capt.
Leith, Allan Ramsay.
Lewis, Gerald Breton.
Loudon, David McKinlay.
Muil, James, jun.
Nicholson, John.
Palmer, Stanley Tom.
Pearson, Albert Edward.
Pilkington, Garnier David.
Plyer, Donald Challis.
Pryke, Denis.
Rimmer, George Mervyn.
Robson, Harold.
Sangster, Charles Low, B.Sc.(Eng.).
Taylor, Percy Heatley, B.Sc.(Eng.).
Whisson, Leslie Bartlett.
White, George Edward B., B.Sc.(Eng.).

Student to Associate

Black, William David.

The following transfers were also effected by the Council at their meeting held on the 27th April, 1939:—

Student to Graduate

Aird, Robert Harker, B.Sc.
Albuquerque, Robert Francis.
Allen, Alexander Miall.
Ames, Eric Cuthbert, B.Sc. (Eng.).
Bana, Sorabji Dorabji, B.Sc.
Bawtree, Keith Ormsby, B.Sc.(Eng.).
Bellamy, Charles Lang.
Blakeley, Philip William.
Brooker, Frederic Edwin, B.Sc.Tech.
Canning, Randall George.
Carlaw, Arthur Donald.
Clark, James Randall E., B.A.Sc.
Coates, Peter John H.
Collier, John Archibald, B.Sc.
Cook, Ronald Leslie J.
Cross, Donald Ewart, B.Sc. (Eng.).
Crow, Denis Raymond.
Dissanayake, Sirisena.
Dronnikoff, Serge Nicolas.
Fraser, James Anderson.
Gardner, Thomas.
Garnett, William Lindow.
Gray, Dudley Maurice.
Gupta, Jagan Nath.
Harris, Douglas John, B.Sc.(Eng.).
Hartill, Philip.
Lee-Richards, Kenneth Leonard, B.Sc.
Lloyd, William John, B.Sc. (Eng.).
Lowe, Richard Arnison, B.Sc.(Eng.).
Madhavan, V.
Magee, James Frederick.
Malhotra, Krishan Kumar.
Mouat, William Neils.
Ochani, Utamsing Gurmukhsing, B.Sc.(Eng.).
Osmand, Alexander Gordon, B.Sc.(Eng.).
Oxley, Jesse.
Patchett, Gerald Norman, B.Sc.
Peterson, Roland James, B.Eng.
Pipkin, Frederick Ernest R.
Pocock, Sydney Norman.
Pybus, Jack, M.Sc.
Rama Murty, Nelamangala Vuddi S.
Rao, Guthikonda Virabhadra.
Rehfisch, Thomas Julius, B.Sc.(Eng.).
Samuel, Samuel John.
Sarwate, Manohar Balaji, B.Sc., Ph.D.
Seethapathi Rao, Devaguptapu.
Shah, Shantilal Amarchand.
ShanKaran, Alladi.
Strachan, Thomas Alexander.
Swamy, S. V. Venkatarama, B.Sc.
Tata, Adi Bejan.
Thomas, John Charles.
Twidale, Denis Baron.

Student to Graduate—continued.

Vaidyanathan, N.
Vallis, Frank.
Wakefield, John Anthony.
Webb, Herbert Leslie, B.Sc.(Eng.).
Wilding, Albert John F.

At the Annual General Meeting of The Institution held on the 11th May, 1939, the following elections and transfers were effected:—

Elections

Member

Kallir, Ludwig.

Associate Members

Barker, Hugh Purslove.
Bannister, Charles Robert, B.Sc.
Cryan, William John, Capt.
Dallimore, Leslie Millward.
Fewings, John Thomas.
Gawthorne, Leslie Everard.
Groome, Robert Aubrey, B.Sc.(Eng.).
Gyr, Walter.
Haefely, Guido Emile, Dr.Ing.
Harle, Andrew Haig, B.Sc.
Hood, John Leslie, B.Sc.
Jacob, William Gordon R.
Johnston, Reginald James, B.Sc.
Lister, Bertie.
Lister, Harry.
Lister, John.
Lowne, William Robert J.
Martin, George Harold.
Meyer, Fenwick, B.Sc.
Morris, William Idwal, M.Eng.
Needham, William, M.Sc.
O'Shea, Micheal, Capt.
O'Sullivan, John Patrick, Capt.
Ray, Laurence Arthur.
Sang, Ram Parshad, M.Eng.
Schiller, Paul, Dipl.Ing.
Tattersall, Henry Waud.
Whitwell, George Anthony, B.Sc.
Woffendale, Harold Aubrey, B.Sc.
Woodhead, Harry Stanley.

Associates

Calvete, Isidoro Bibiano.
Cusack, Owen, Capt.
Day, John Charles.
Griffiths, Thomas Daniel.
Goulston, Philip Nigel.
Longson, Harold Howard.
Melia, Charles John.
Millatt, Harold Walter.
Quigley, Matthew Michael, Capt.
Robinson, William Brian.
Sajnani, Narain Bansiram, B.Sc.
Sammut, Carmelo.
Steward, Stanley Feargus.
Tarry, Edwin Samuel.
Tetlow, Norman, B.Sc.
Thompson, Victor Charles.
Wordham, Charles William.

Graduates

Baboo, Sreeperumbudur Culasekara.
Bahl, Kidar Nath.
Bomford, Kenneth David, B.Sc.
Brooks, Harry William.
Cash, Thomas William.
Charles, Robert Frederick.
Collinson, William.
Gilchrist, Stirling.
Graham, Edmund Ian H.
Greer, Norman Campbell.
Hands, Robert Claude.
Jog, Balkrishna Laxman.
Jolin, Charles Philip, B.Sc.
Leigh-Clare, Harry Howard J., B.A.
Lenkowski, Joseph.
Lord, Harold Gordon.
Makodzub, Daniel Mark, B.Sc.(Eng.).
Marathe, Gopal Mahadeo.
Mill, Alexander.
Norrish, George Charles W.
Old, Brian Willmore, B.Sc. (Eng.).

Graduates—continued.

Percival, Frank Vernon, B.Sc.(Eng.).
Perry, Percy Charles A., B.Sc.
Pickering, Ernest Roy, B.Sc.
Prasanna, Gorur Roysm S.
Rao, Raghunatha Sreenivasa.
Raymond, Ivan Victor.
Reddy, S. R. Vithoba.
Riddell, William Forster.
Scanlan, Patrick Michael J.
Sedgley, Henry.
Stafford; Albert, B.Sc. (Eng.).
Tsong, Tuh-Zung.
Yates, Henry Donald A., B.A.
Yuan, Lun-Nee.

Students

Adams, Charles Eric.
Ahmed, Iftikhar Ud Din.
Ahmed, Waquar.
Aiyar, Bhagavatheeswara.
Ashraf, Shiakh Mohamed.
Awan, Bashir Admod.
Badami, Fidahusein Vallimahomed.
Bailey, Eric Charles.
Barnes, Robert.
Bashyam, V. Renga.
Bentley, Robert.
Beri, Prakash Chand.
Betts, Edgar Newman.
Bhardwaj, Amar Singh.
Bhatt, Santilal Nandial.
Bhattacharyya, Paresh Chandra.
Bhide, Ramachandra Dattatray.
Bloodworth, William Aspin.
Bose, Protul Krishna.
Bowden, William Howel J.
Brownfoot, Spencer Harold.
Burnett, Roy Rutherford.
Byrne, Joseph.
Case, Francis Charles.
Chakrabarti, Sailendra Nath.
Chandler, Edward Anthony.
Chapman, William James.
Chowdhury, Jagadish Chandra.
Clarke, Lionel Gregory.
Cook, Thomas James.
Corfield, Norman Mason.
Dandekar, Chintaman Damodar.
Daruvala, Homi Sorabji.
Davidson, Duncan Hector.
Dhawan, Prem Lall.
Dube, Anand Shanker.
Dutta, Byom Kesh.
Edwards, Allan Hugh W.
Edwards, David George.
Entwistle, William Ewart.
Everett, Dennis Mackworth.
Franklin, Edward Beaumont.
Gogte, Vaman Mahadeo.
Gupte, Madhukar Shankar.
Gandhi, Dhirajlal Virpal.
Gazder, Keki.
Ghelani, Gulamali Ratanshi.
Ghosh, Bimal Chandra.
Gonsalves, Hubert Leslie.
Govila, Chandra Prakash.
Gupta, Bibhuti Bhushan.
Hand, Raymond Wilson.
Haynes, Brian.
Hitchcock, Edward Hamilton.
Hood, Eric Herbert.
Husain, Mehdi.
Husain, S. Nasir.
Husain, Sayyad Farhat.
Jain, Abhimannu Kumar.
Johnson, Leonard.
Jones, James Mason.
Jungalwalla, Ferdoon.
Kapur, Ram Parkash.
Karanjia, Kaikhushru Framji.
Karnik, Veshvant Gopal.
Kirpalani, Ramchand Tourmal.
Kitchen, Clifford James.
Lewis, Jack Leslie.
Lobo, Valerine.
Long, James.
Mahan, Robert Clifford.
Mainkar, Lachmansingh K.
Major, William.
Mallikharjuna Rao, Yarlagadda.
Mathur, Prakash Govind.
Maunder, Augustine Hamilton, B.Sc.
Middlemiss, Ernest Joseph.

Students—continued.

Minocherhomji, Behram Framroze.
Morgan, James Leslie.
Mothe, Venkata Subba Rao.
Motivala, Jagamohandas Bhavanidas.
Mukerjee, Arun Prakash.
Myerson, Ronald James Wesley.
Nair, Narayana Janardhanan.
Nalam, Venkatarayal.
Namby, T. V.
Newsome, Arthur.
Norton, Edward Richmond.
Pardeshi, Tukaramsing Ratanasing.
Pathak, Pushkarrai Dalpatram.
Paynter, Douglas Arnold.
Pearson, John Stansfield.
Pikett, Cecil Charles.
Porter, Albert Henry J.
Prasada Rao, Kambhammettu Anjaneya V.
Pugh, Terence Francis H.
Pularu, Ram Prakash.
Quance, Gordon Courtenay.
Rajamanya, Shankar Mahadeo.
Ranganadha Rao, Immaneni Venkata.
Rao, Nelamangal Shamarao S. N.
Reddy, Pappu Lakshminarayan.
Redgment, Peter George.
Rege, Bhalchandra Shanker.
Reynolds, Sydney McGregor.
Richardson, Alan.
Richardson, Percy.
Rosenblum, Benjamin.
Samuel, Nallatambe.
Sampat, Jayant Krishnadas.
Sanders, John.
Seear, Stanley Charles.
Shah, Muljeebhai Manilal.
Sharma, Tarachand.
Sheard, Leslie.
Shepherd, John William A.
Shroff, Homi Sorabji.
Silva, Joseph Cyril W.
Singh, Pardaman.
Smelt, Cecil.
Sreeramulu, Kandarpa.
Sthaleker, Bhawani Narayen.
Suthar, Dhansukhlal Samaldas.
Talwar, Chaman Lal.
Taylor-Cannon, Lewis George.
Thomas, Puthenveetil Abraham.
Thompson, Douglas Herbert.
Turner, Ronald James.
Vasan, Subramonia Srini.
Veeraraghavan, S.
Veeraraghavan, Viravanallur Srinivasaraghava.
Venkataramania, Tarikere R.
Venkoba Rao, Dasarathi Rao.
Viswanathan, Tirunelvelly Sankara.
Vyas, Chandrakant Karunashanker.
Walker, Harry.
Waller, Francis.
Walters, Harold Stanley.
Watson, Philip Alexander.
Weaver, Donald George.
Winfield, Stanley Joseph.

Transfers

Associate Member to Member

Allibone, Thomas Edward, D.Sc., Ph.D.
Casse, Clifford William.
Collyns, Charles Henry A.
Couch, William Charles M.
Daniel, Thomas Ernest, M.Eng.
Field, Douglas Conan, B.A.
Freer, Robert McDonald.
Green, John Douglas.
Griffith, Charlie.
Hill, Edward Percy, M.Sc.Tech.
Hyde, Cecil Lewis G., B.Sc.(Eng.).
Long, Herbert Howard.
Mellonie, Stanley Richard.
Miller, Eugene Herbert.
Pritchett, Cyril George F.
Purser-Fletcher, Frank, O.B.E.

Associate Member to Member—continued.

Shaw, James Ernest, M.Sc.
Simpson, Clement Maurice, Col., M.C., R.E.
Smart, Geoffrey William, B.Sc.
Sparks, Cedric Harold, M.A.
Warburton, John Henry, B.Sc.(Eng.).
Woods, Fitzroy.

Associate to Associate Member

Brocklebank, John.
Grafton, Reginald Hannaford.
Gunn, George.
Hardman, John.
Hosking, Orlando Henry.
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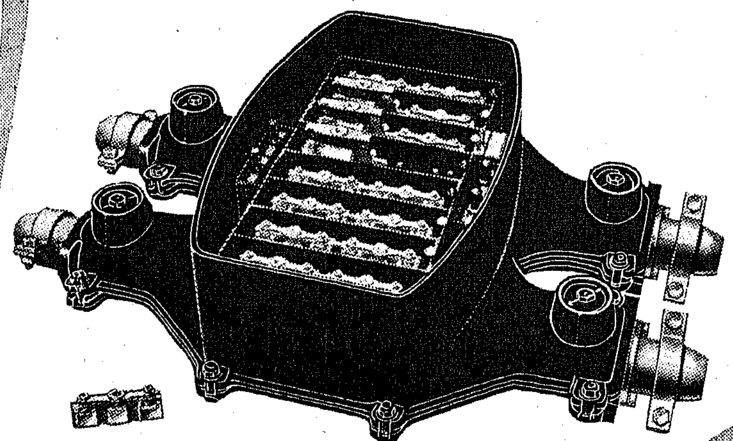

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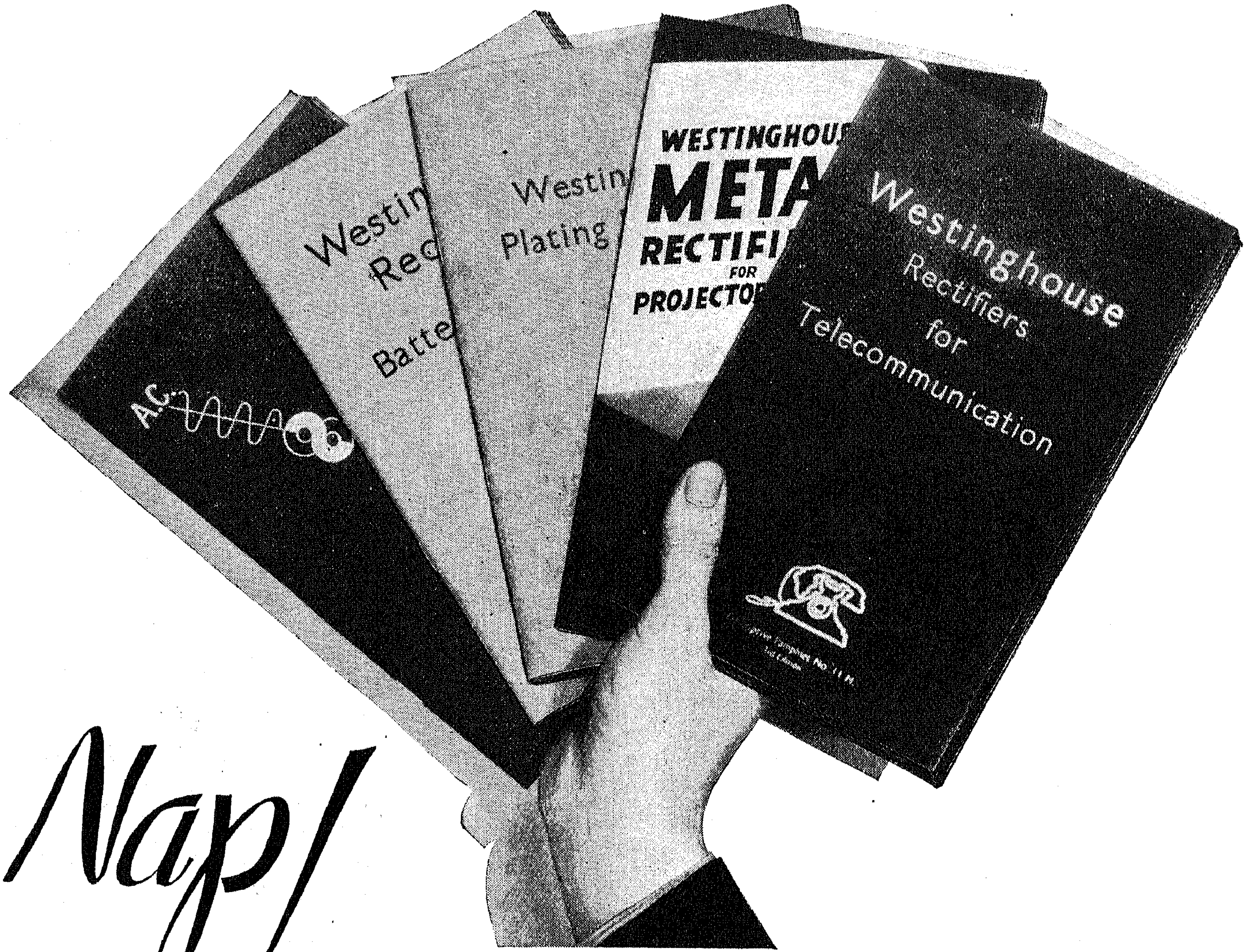

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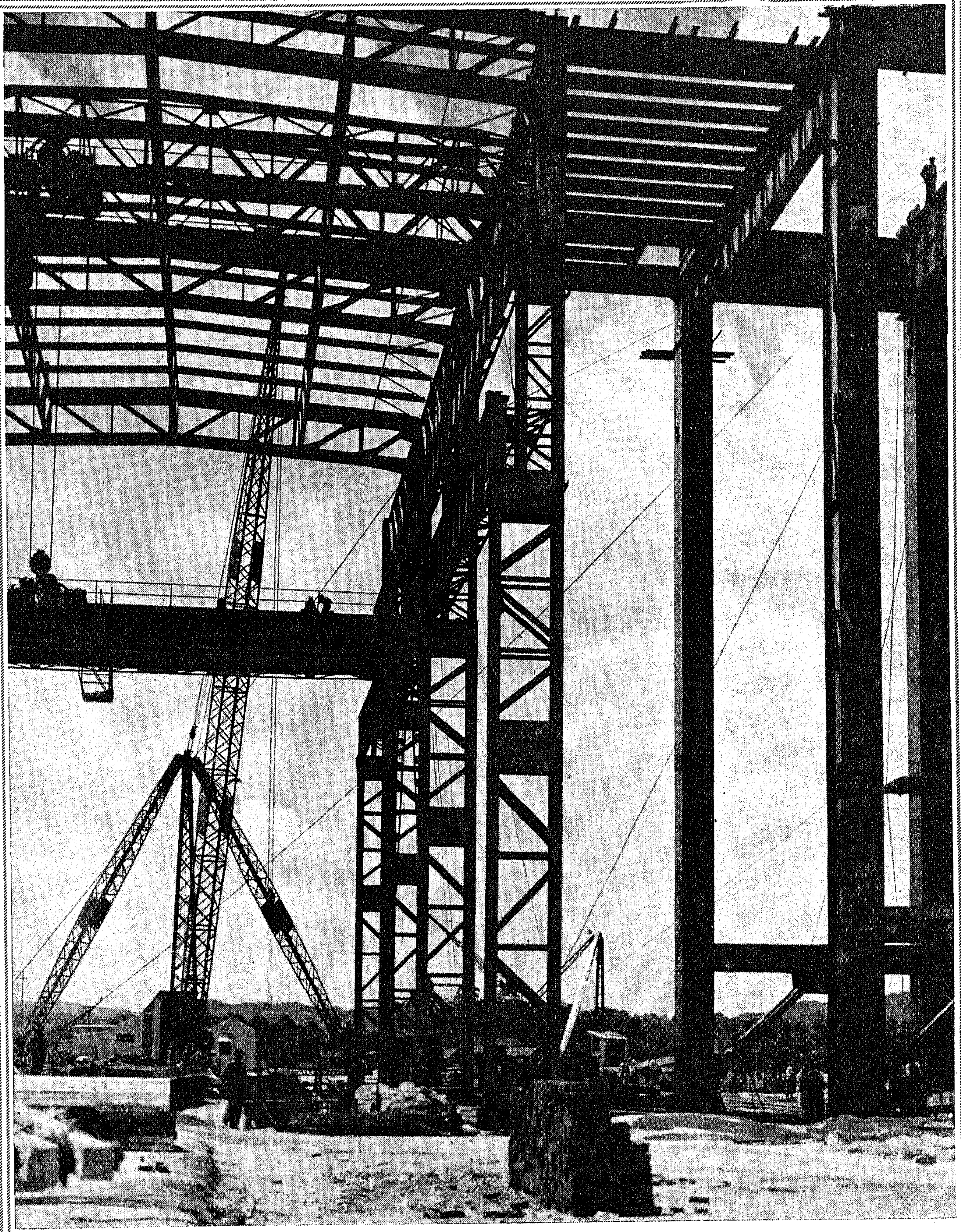

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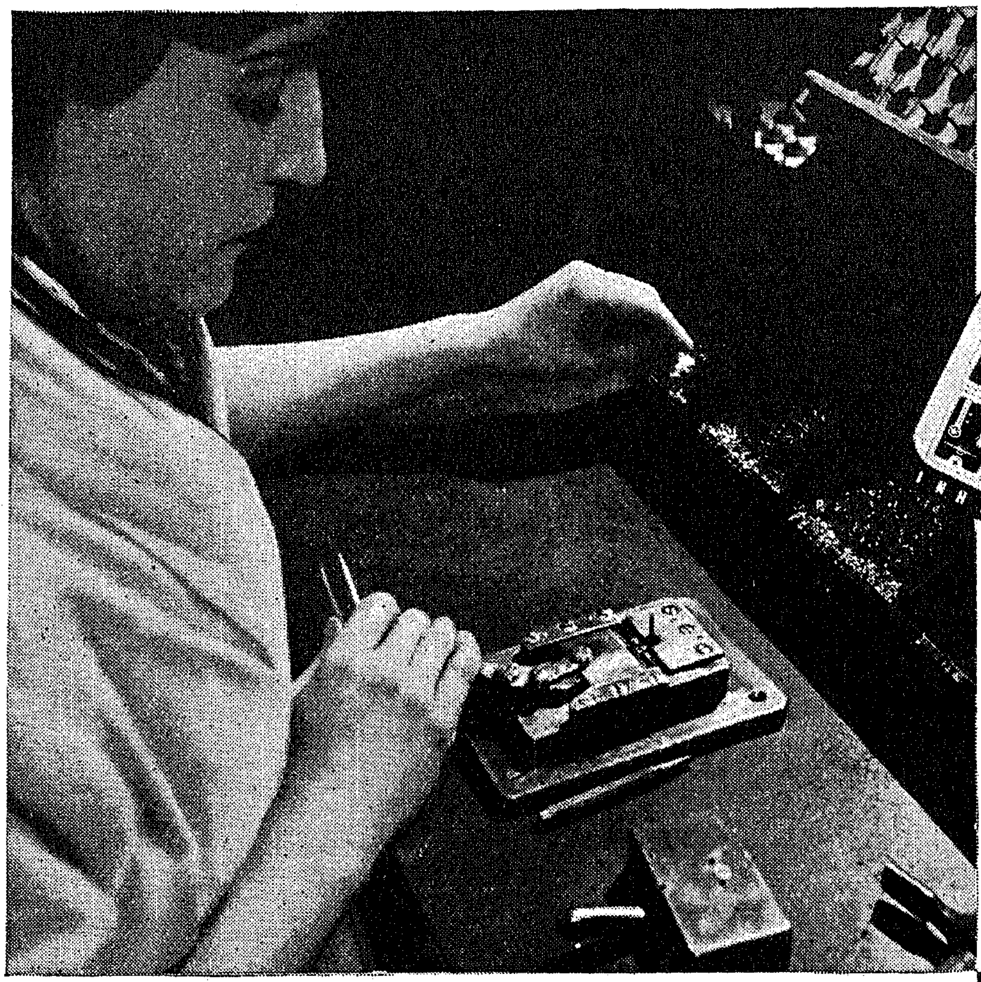

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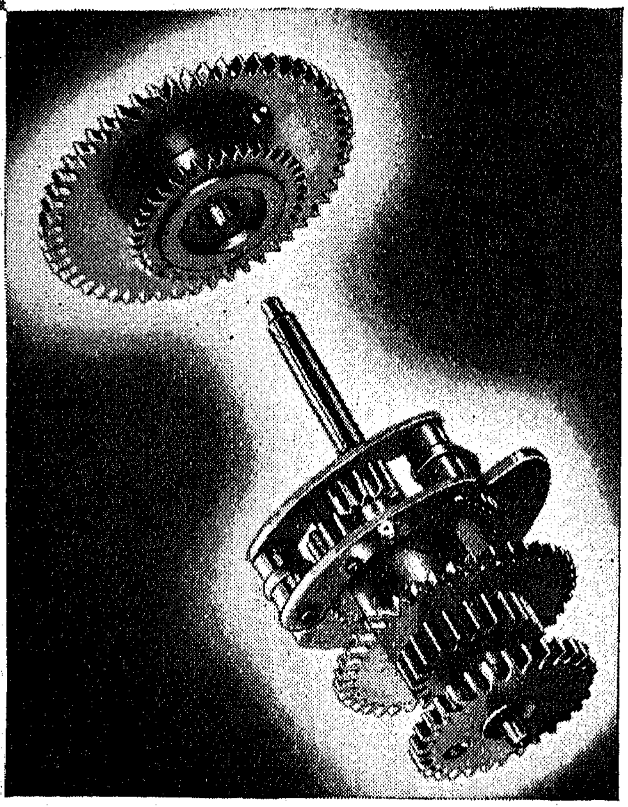

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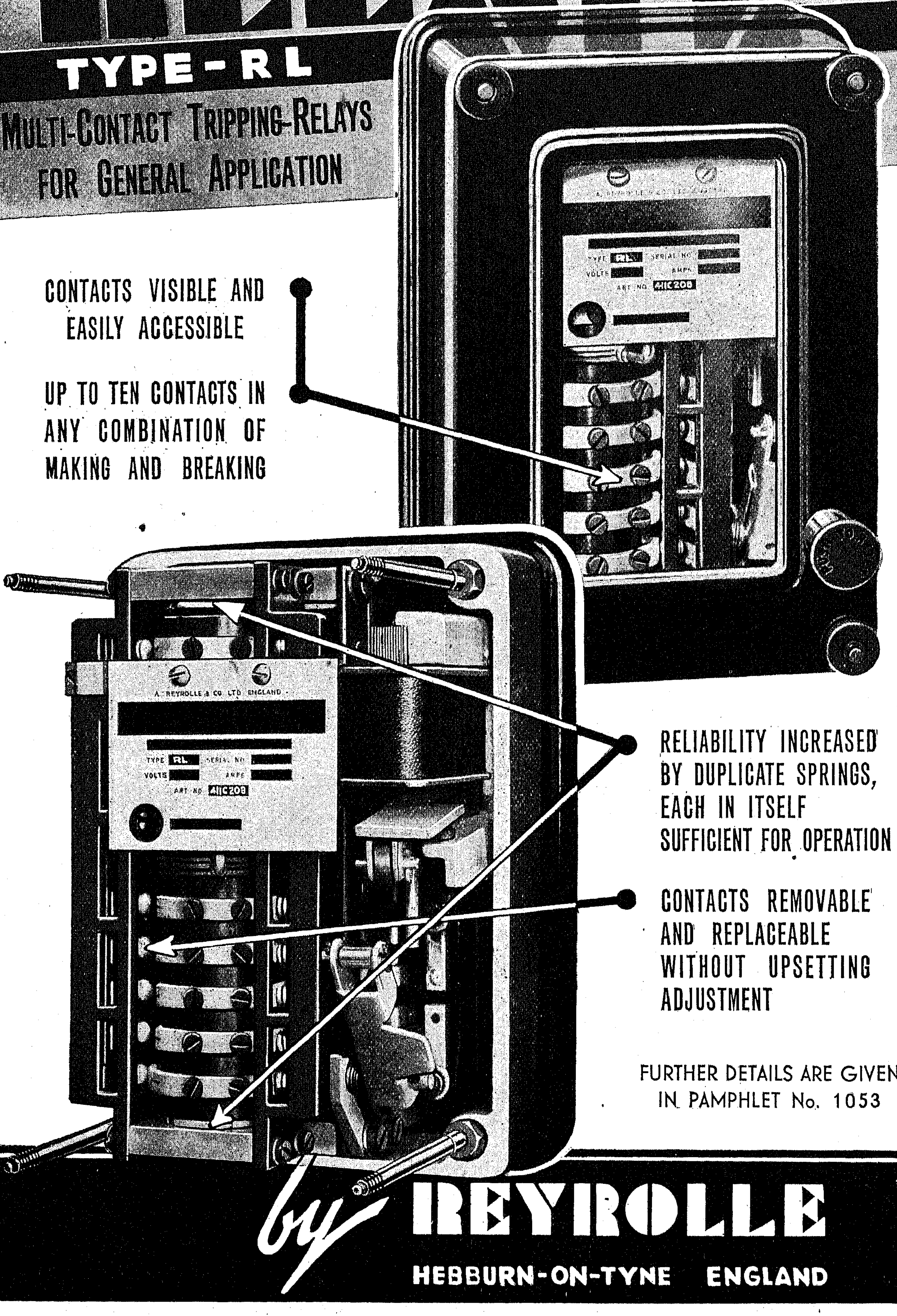

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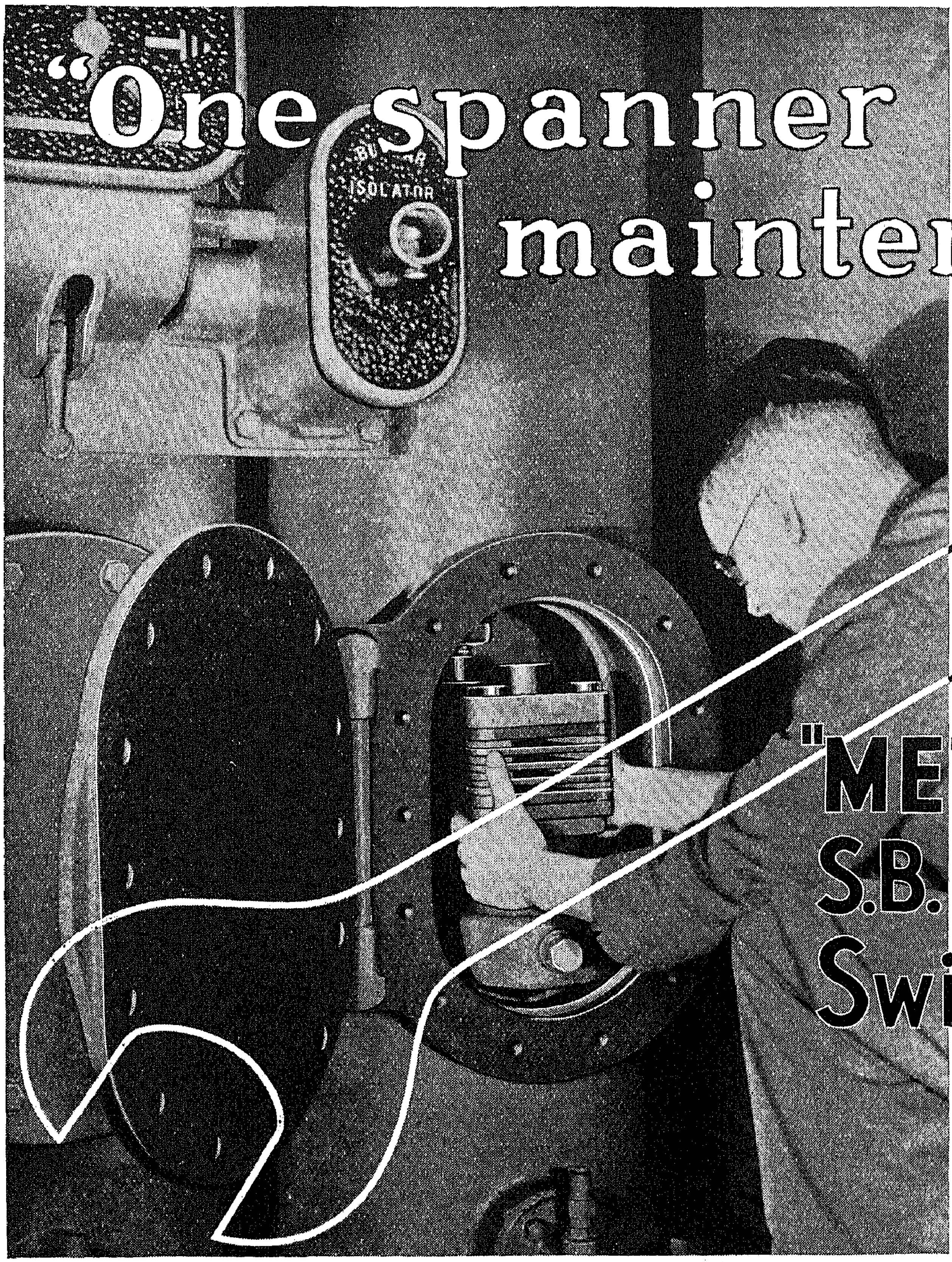

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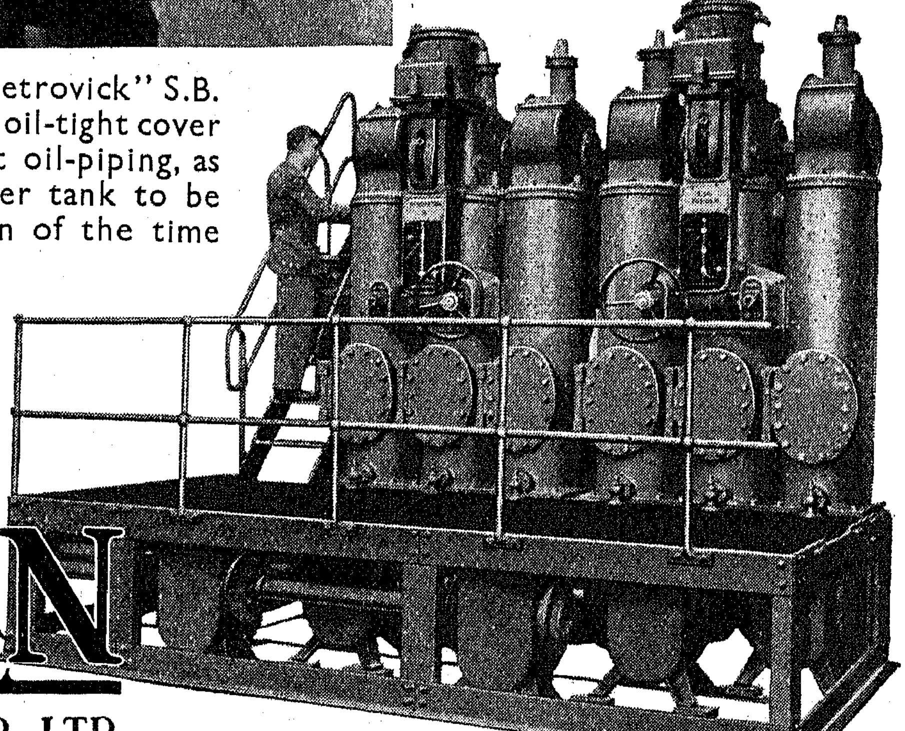

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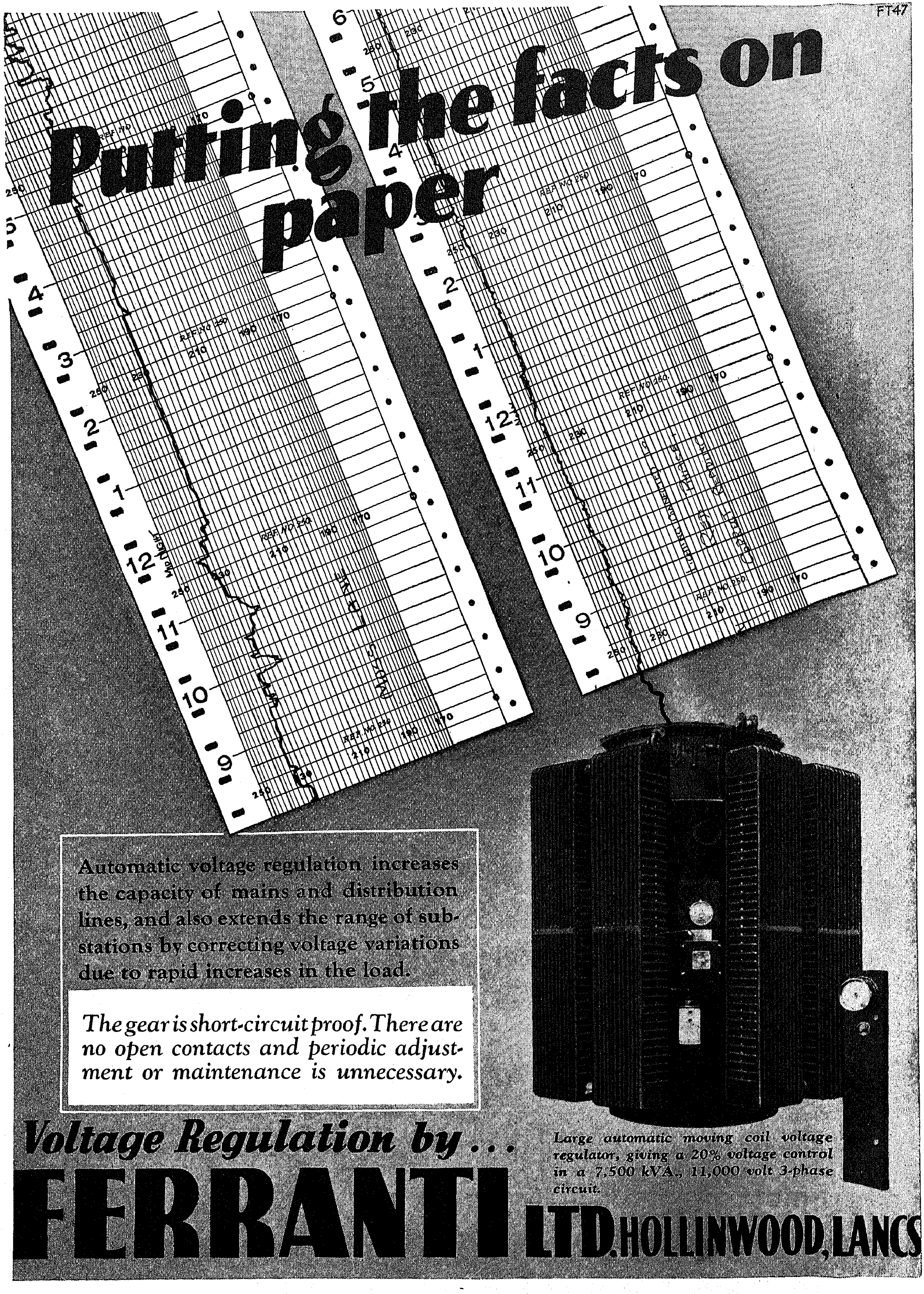

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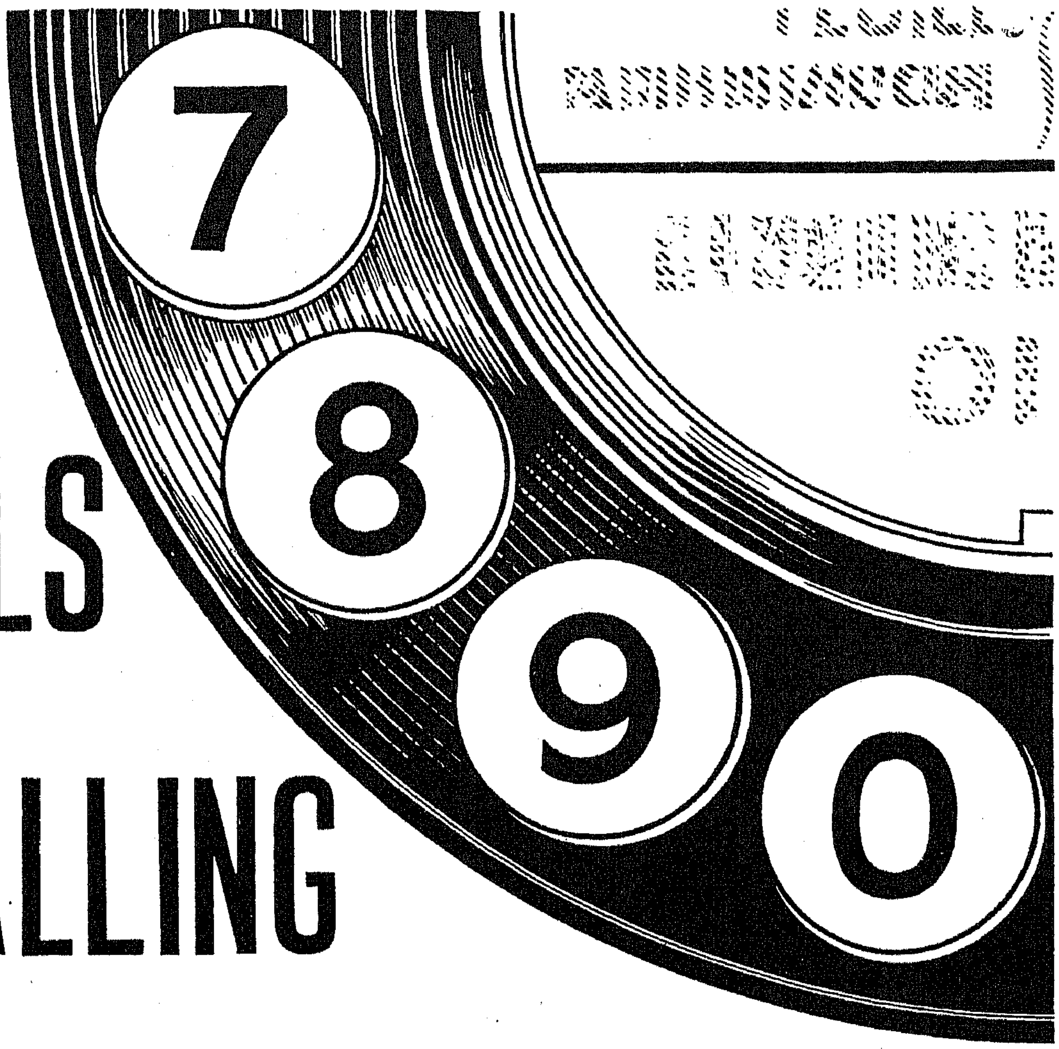

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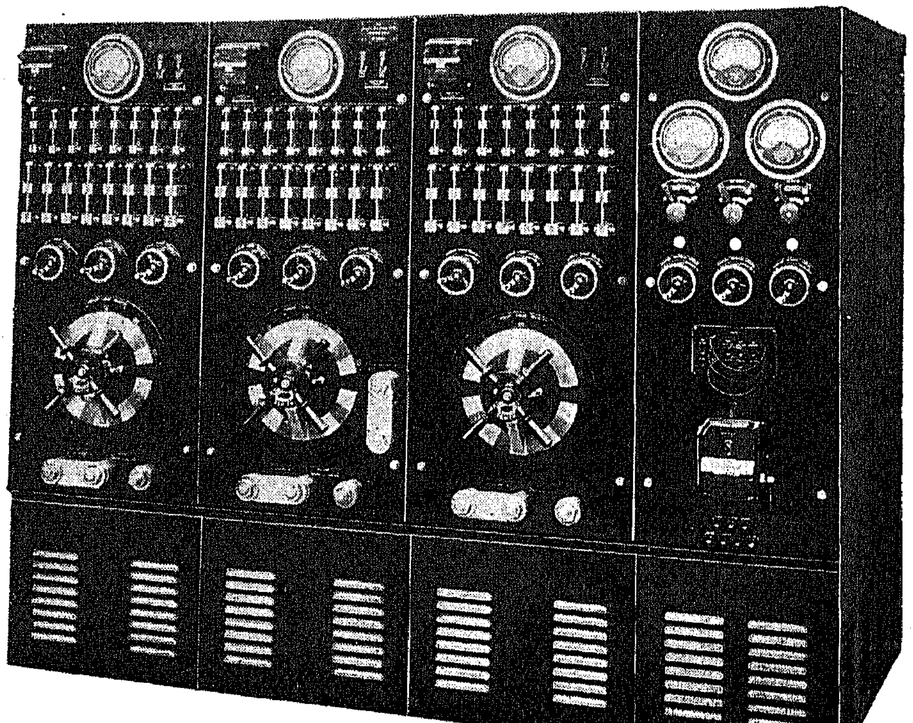

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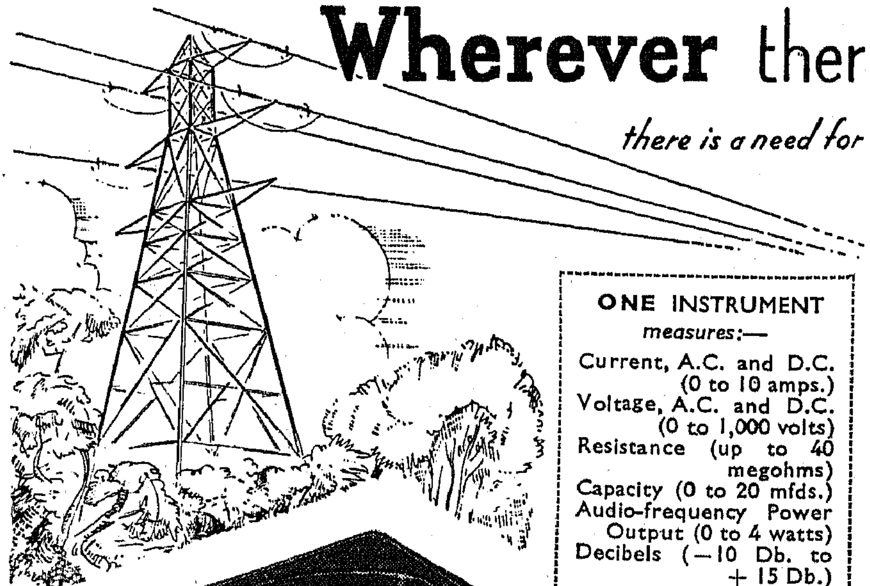

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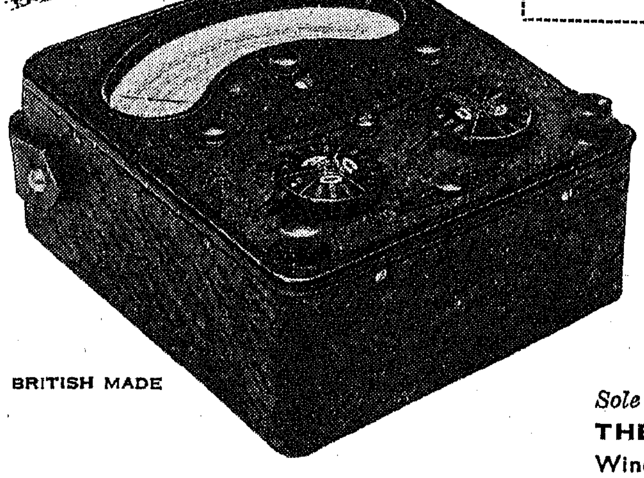

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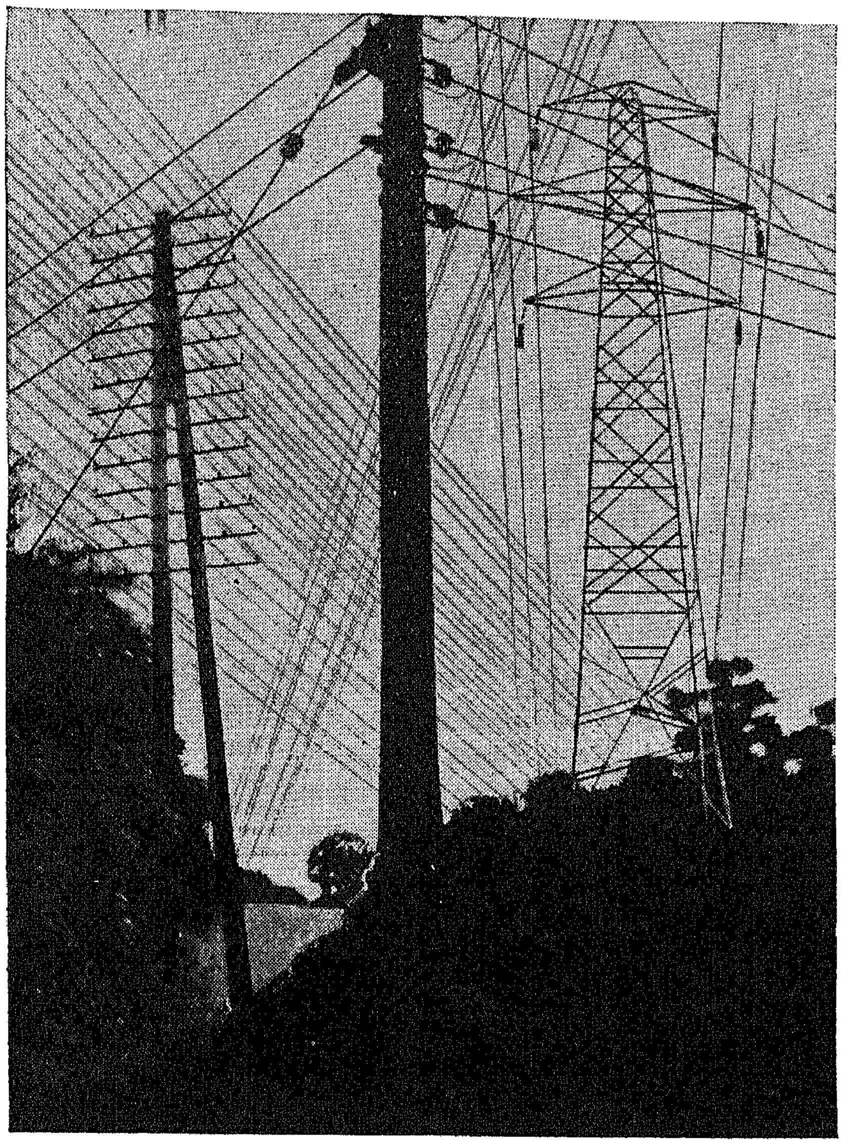

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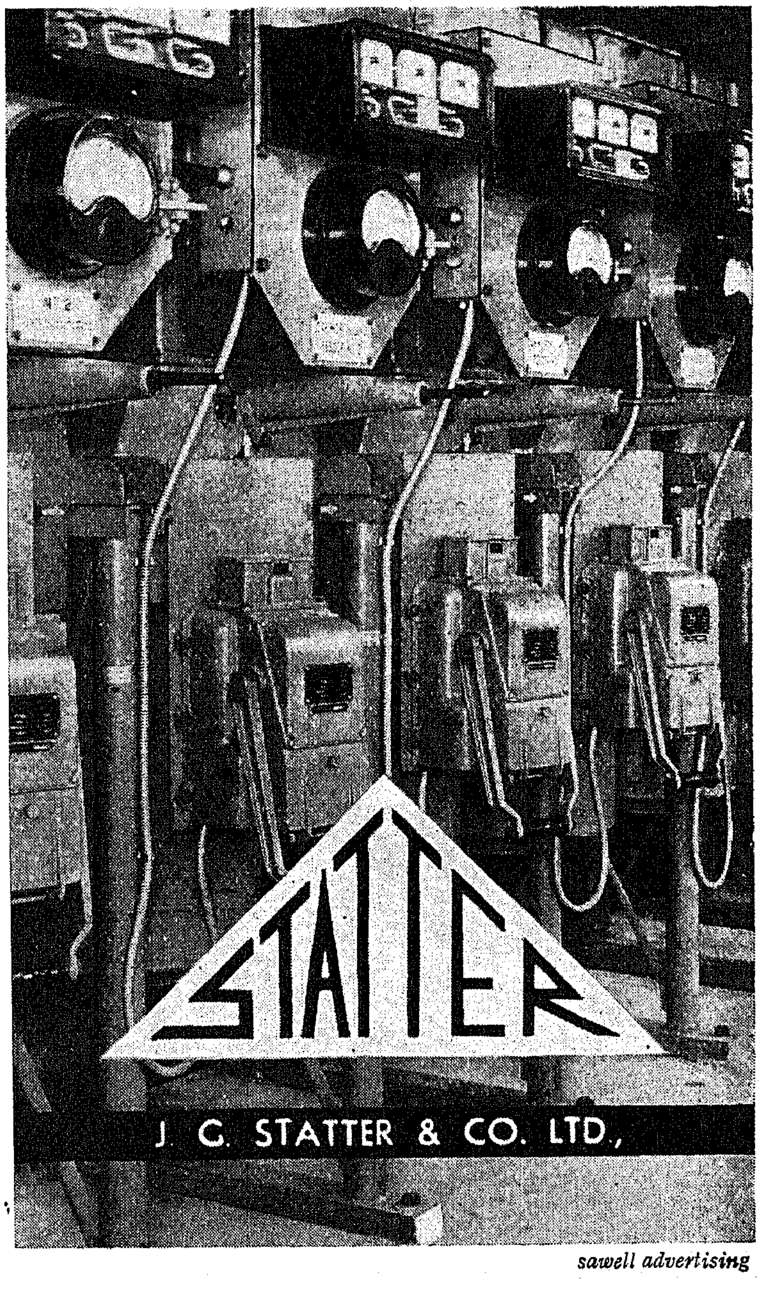

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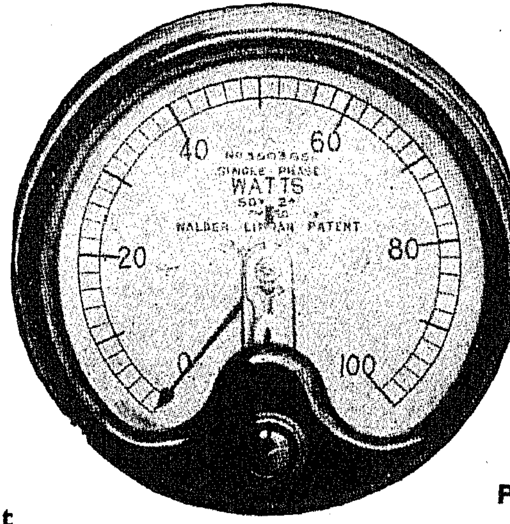

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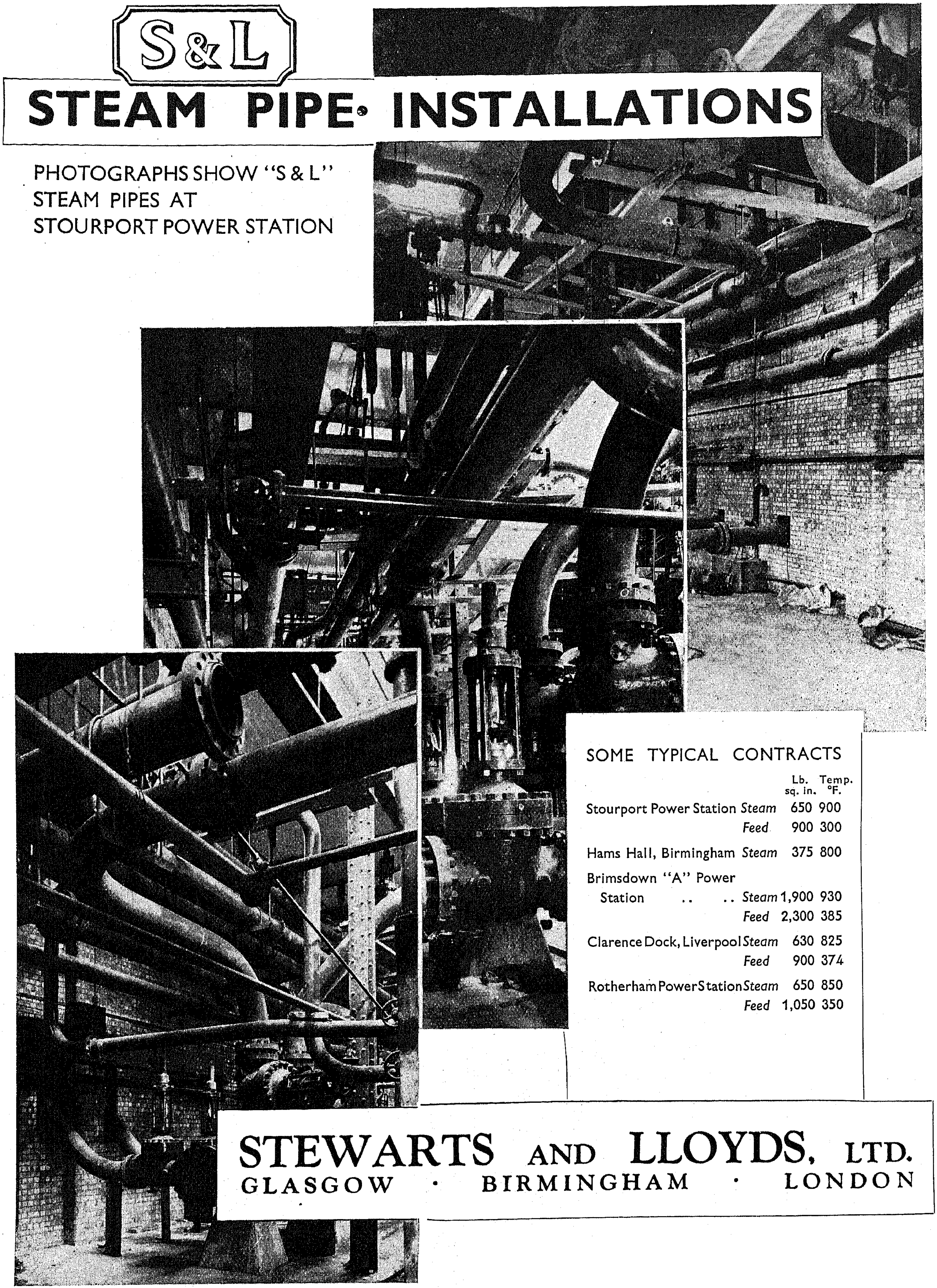

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